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A COMPUTER PROGRAM FOR ANALYZING THE ENERGY CONSUMPTION OF AUTOMATICALLY CONTROLLED LIGHTING SYSTEMS

FINAL REPORT*

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PROJECT SUMMARY

This report marks the completion of a more than three-year relationship between Lawrence Berkeley Laboratory (LBL) and the subcontractor, Smith, Hinchman & Grylls Associates, Incorporated (SH&G).

The major task under this subcontract was the development of a computer program that would predict the performance of controlled lighting systems with respect to their energy-saving capabilities. Paralleling the work at SH&G on the development of the computer program, two site installations were being set up and monitored by LBL. A low-voltage switching system was installed on the 58th floor of the World Trade Center in New York, NY, and a dimming system was installed at the Pacific Gas and Electric building in San Francisco, CA. SH&G played a consulting role for these field installations, insuring that the physical measurements taken were meaningful and could be used to assess the accuracy of the computer model being developed. Long-term real physical measurements have not been completed. Thus the program cannot yet be verified for a full year compared to actual physical measurement. Several trips were made to both sites throughout the course of this project to review the installations and to discuss progress being made at SH&G and LBL.

Principal SH&G personnel performing the contract work were Mr. Martin McCloskey and Mr. Steven Stannard. LBL's technical expert on the project was Mr. Francis Rubinstein, under the supervision of Dr. Rudy Verderber.

I CONCEPTUAL FRAMEWORK OF THE PROGRAM

INTRODUCTION

As the cost of energy continues to increase, sophisticated lighting control systems designed to minimize energy consumption are proving more cost-effective. If a designer is to evaluate the performance of lighting control systems for their energy-saving capabilities, an unbiased mathematical model which compares different control systems on an equal basis is an important tool. The purpose of the computer program described in this report is to provide that model.

In theory, a lighting control system which continuously monitors the available artificial and natural light within a space and supplies only the power required to provide light to meet some specified criteria illuminance level, and no more, should be able to optimize the energy-saving capabilities of that lighting control system. Because of the potential for constantly varying power consumption due to this Equi-Illumination Dimming (EID) system, the computer is employed to help in modeling the performance of these types of systems.

The computer program discussed here provides a mathematical model from which comparisons can be made, on an economic basis only, of how different systems perform. The program does not calculate daylighting, but rather uses daylighting values as input. Just as with any model, results obtained can only be as reliable as the input used to generate these results. Calculations can also be done on simple control systems which do not respond to daylighting.

The program analyzes control schemes exclusively on an economic basis, considering only the energy consumed directly by the lighting system. No attempt has been made to account for any additional savings realized in HVAC systems when lighting systems are controlled. The program makes no statement about the user acceptance of lighting control systems or about the aesthetic qualities of the use of daylighting within interior spaces.

The major components of the program are discussed in this documentation. Several examples are included to explain how to run the program.

LIST OF SYMBOLS AND VARIABLES

E_c - A value in footcandles which is the criterion illuminance value to be maintained over some specified time span. This level is to be maintained by the combined contributions of natural and artificial light.

E_n - A value in footcandles which is the amount of natural light available from daylighting contributions at any point in time. A continuous curve of this value is constructed from a few input data points for three days during the year.

EID - Equi-Illumination Dimming is the concept of lighting control systems for which this program was particularly developed. A sensing device monitors all available light within a space. As E_n increases or decreases, the light output and consequently the power input of the artificial lighting system is altered to maintain a specified criterion illuminance value.

MF - Maintenance Factor. A number expressing the combined effect of all factors contributing to a decrease in total light output of an artificial lighting system over time. Year-end values for a five-year period are expected input.

THEORETICAL BASIS OF PROGRAM

A paper written by Mr. Steven Stannard entitled "An Economic Analysis of Supplemental Skylighting for Industrial and Office Buildings", which appeared in the July, 1979 issue of the Journal of the Illuminating Engineering Society served as the theoretical basis for this computer program. Certain additions and deletions have been made in what now constitute the final mathematical model used, and these changes will be discussed herein.

Power Input vs. Light Output Relationship

The program can analyze any one of three power input vs. light output relationships: continuous dimming with a linear response, continuous dimming with a non-linear response, or discrete stepped response. The linear case is treated as in Stannard's paper, with the maximum and minimum values of power input and light output being all that is needed to describe the complete relationship. Non-linear response is described by linear interpolation between ordered pairs of power vs. light which describe the curve, and the stepped response also consists of a number of ordered pairs. Any of these options can be used with or without daylighting, and thus, there are six distinct modes of control system operation.

Daylighting Curve Fitting Over a Day

A sin series of the form shown in the paper is still used to fit the input daylight values over the course of a day. At the user's discretion, more than three values can be used to build the curve. It is assumed that solar sunrise and solar sunset have values of $E_n = 0$ so that if three values are input, a total of five points are available to construct the curve.

Describing a Control Scheme

A complete control scheme for some given space may have up to seven different control days that are assumed to occur each week throughout the year. A control day consists of a unique E_c histogram and an associated energy cost rating block structure for that day. The constraint of one criterion value from start to stop is no longer necessary, and any combination of time blocks with varying values of E_c can be specified and analyzed.

Daily Energy Consumption

In determining total daily energy consumption for a day, one needs to know the power required to supply some level of aritificial illuminance and the times interval that that power is required. The method of Fourier series integration which was used to get the total energy value as the "area under the curve" proves too cumbersome when multiple E_c blocks are allowed, and a slightly different approach has been taken. The algorithm now used for each control day can be described as follows: Each separate time block specified with its unique E_c and dollars/KWH value is divided up into a number of smaller equal time zones (currently 50). Throughout any block, a constant E_c value and cost/KWH value exist, by definition. If daylighting is present, the E_n curve is interpolated at the center of each small time zone to get a value of E_n available during that time zone. Knowing this value and the required E_c, $E_c - E_n$ becomes the amount of light which must be supplied by the artificial lighting system. Knowing the power input vs. light output relationship, the amount of power required to supply this level can be calculated and knowing the time increment, the energy follows directly. Moving from zone to zone across the time scale for the entire day enables the total energy value for a particular control scheme day to be calculated. This value is then weighted by the total number of days per week that that particular control scheme is used.

This same process occurs of each separate control day and the weighted sum of all such control days becomes the representative daily energy consumption value for that day. This process occurs for four days during the year when daylighting is present; March 21, June 21, September 21, and December 21.

Maintenance Factor

As light output depreciates over time, more power is required to provide a specified value of aritificial illuminance, and thus, the maintenance factor plays a part in total energy consumption and the costs associated with it. The effect of maintenance factors is treated as described in Stannard's paper for all control system modes except one. In the case of stepped control response where no daylighting is present, the maintenance factor is not considered. Such systems usually respond to a specified power input scheme and stepping to higher levels of light as the system depreciates below original E_C values is not done.

Yearly Energy Consumption

As elaborated in the enclosed paper, total energy consumption values for the solstices and equinoxes serve as the data points to build a curve of yearly energy patterns. From this curve the technique of Fourier series integration can be used to give monthly or yearly values of energy and operating costs. As daylighting conditions can be broken up into clear and cloudy days, a separate curve is generated for each condition and weighting factors on a monthly basis are used to determine the net effect.

Economic Analysis

The program now incorporates a life cycle cost model to enable the designer to compare different systems on an economic basis. Yearly operating costs are calculated in conjunction with energy consumption values, and the operating costs of the base and controlled systems are known. In addition, initial costs associated with a control system can be specified, as well as a salvage value of the equipment at the end of its economic life. Present Worth and Savings Investment Ratio techniques are employed to give two separate methods of economic comparison of a controlled lighting system against baseline conditions.

Summary

The main theoretical concepts presented in Stannard's original work have been incorporated and expanded upon in this computer program. The uncertainty of the reasonableness of only three daylight values being used to describe the entire day has been removed by allowing for more input points. It remains to be seen whether only four days of information per year are enough to describe yearly variations. Ongoing field tests to gather actual measurements will help in that assessment, and even if more days are deemed necessary, the basic theory remains the same.

ASSUMPTIONS USED IN THE COMPUTER MODEL

There are several assumptions used in this computer model which the user must be aware of in preparing to do analysis. These assumptions are listed in order of importance with respect to their effect on producing useful results.

1. The Creation of E_c Histograms for Control Schemes, and Corresponding Input Values of E_n are Meaningful and Relate to the Same Sensor Point or Area in the Controlled Space.

The theory of an Equi-Illumination Dimming (EID) control system is that somewhere within the space there is a sensor which monitors available light, both artificial and natural and supplies information to the artificial lighting system as to how much light (and, thus, power) is required to maintain a certain criterion level E_c of illuminance. Often the sensor cannot be placed directly at the location where constant illumination is desired, such as on a desk top. The sensor need not necessarily be at the location of the desired E_c, but what must occur is that the relationship between what the sensor reads and the variation in the light level at the actual point of concern must be a linear relationship. If a sensor looks at the variation in wall luminance, for instance, changes in that value must relate to a proportionate change which would occur at the actual point of concern. For example, if the sensor monitors 70 footlamberts when there are 70 footcandles provided on the desk surface where a constant level is desired, the sensor should monitor 10 footlamberts when there are 10 footcandles on the desk surface.

Related to this is the requirement that all specified values of E_c, calculated values of E_c, and the value of maximum artificial illuminance available must all relate to the same point or group of points. If the sensor monitors what happens on a desk surface, the criterion illuminance histogram should be constructed for that location, daylighting calculations, if needed, should be done to give E_n values at that location, and the value of maximum artificial footcandles available should also be at that location. One cannot expect an accurate model of the performance of the control system if all of these parameters do no relate to the same point in space. If the user remembers that according to the EID theory, every E_n footcandle available will directly replace the need for some artificial lighting and, consequently, the power required to supply that light, then this assumption should not present any problems to the user.

Note: Although throughout this report the EID system is being discussed in terms of providing constant values of classified footcandles, this is more of a practical requirement than a theoretical one. If the mechanisms were available which could maintain constant visibility, for instance, or constant Visual Comfort Probability (VCP), then the model of this program could still be used but put in terms of this other parameter rather than footcandles. It is felt that for the foreseeable future, EID systems based on classical footcandles will be the most common types of systems.

2. Control System Response to Changes in E_c is Instantaneous, and Actual System Response Follows the Specified Power Input vs. Light Output Relationship Exactly.

This is partly an assumption and partly the nature of the exactness of the computer model which will not be realized in actual physical conditions. If an E_c histogram shows a step function of 50 footcandles up until 10:00 a.m., and then jumps to 70 footcandles, the power requirements associated with that jump will also occur instantaneously and energy calculations will be based upon this change. With a real system, there would be transition time in going from one step to the next and, therefore, measured energy consumption will probably not match predicted energy consumption exactly.

Secondly, the curve which expresses the power input vs. light output response is an ideal expression which will not always be realized in the actual physical condition. The model assumes that the power required to produce a certain level of artificial light to meet some specified E_c will always be supplied correctly with no variation from the curve given. Again, real world conditions will probably not behave as precisely, and so predicted energy savings will vary somewhat from that physically measured.

3. Assume That 4 Days Worth of Daylighting Information is Suitable to Describe the Effects of Daylighting on Total Energy Over the Course of the Year.

This assumption cannot be addressed specifically at this time because long term field measurements have not been taken. With data for September 21 being identical to that for March 21, only three days of information actually have to be calculated. Since for each day of daylighting analysis at least three daylighting calculations for both clear and cloudy conditions must be generated, it is hoped that the current model proves adequate. Presently, even a simple run of the program with daylighting requires 18 daylighting calculations, and if number grows too large, the work involved to run the program may be prohibitive.

4. Maintenance Factors are Assumed to Vary in a Linear Fashion Throughout the Course of Any One Year.

As discussed in the section on the scope of work for this project, a curve fitting technique for maintenance factors was not deemed necessary. It is felt that the assumption of linear variation over the course of the year will pose no problem in program accuracy, and the added flexibility of having easily input intermediate maintenance factors within the five year period of analysis adds to the capabilities of the program.

5. % Clear Sky Input Values Assume Clear Sky Conditions with the Remainder Being a Cloudy Sky Condition.

Partly cloudy daylighting conditions cannot be calculated accurately at present, and thus, all daylighting is assumed to fall into either the clear sky or cloudy sky condition. An input parameter of % clear sky per month determines the weighting for each of these conditions. If and when partly cloudy daylighting conditions can be calculated, the program can be altered to accommodate this change.

DISCUSSION OF INPUT DATA

The program is set up to be able to operate in a completely interactive mode, where the user is at a remote terminal supplying the needed information as requested, or to be run from a data file which has been previously created. In either case, familiarity with the order of input data required is needed, as is knowledge of what each value of input means. To assist the user in this, each input prompt is listed in order of appearance, followed by a brief discussion of what that value means, and the most likely place to obtain that information.

- ENTER UP TO 5 LINES TO BE PRINTED AS HEADING ON THE OUTPUT; NO MORE THAN 80 CHARACTERS PER LINE. ENTER A BLANK LINE AT THE END IF LESS THAN 5 LINES

Rather self-explanatory, this input is simply a way of putting an alphanumeric heading of the user's choosing at the top of the output. For reference, it is helpful if the name of the input file used is included in this information.

- AREA AFFECTED BY CONTROL SCHEME (SQ. FT.)

The total room floor area which is affected by the control scheme is to be input in square feet. With this, system wattage and cost information can be input in on a per square foot basis, which is the way this information is usually available.

- WILL CONTROL SYSTEM UNDER CONSIDERATION BE CONTINUOUS DIMMING OR STEPPED CONTROL?

Depending upon the power input vs. light output relationship of the control system under analysis, an input of either STEP or CONT is sufficient for this question. Depending upon this response, the following information will be asked of the power input vs. light output characteristics of the control system.

- (if stepped control) NUMBER OF DISCRETE STEPS FOR WHICH POWER INPUT VS. LIGHT OUTPUT RELATIONSHIP IS KNOWN

From one to fifteen different sets of ordered pairs of % power input vs. % light output can be input to describe this relationship, and the number of steps should be input here.

- (if stepped control) INPUT ORDERED PAIRS OF POWER INPUT AND LIGHT OUTPUT: POWER (%), LIGHT (%)

The ordered pairs need not be in any particular order but, of course, must be in pairs to insure correct results. For a stepped relationship, these percentage values should be readily accessible from the technical literature describing the control system characteristics. It is important to remember that these values be input as percentage values.

- (if continuous dimming) IS POWER INPUT VS. LIGHT OUTPUT A LINEAR OR NON-LINEAR RELATIONSHIP

A response of either LIN or NON is sufficient for this question. Depending on this response, the following information will be asked of the power input vs. light output characteristics of the control scheme.

- (if linear) MAX. POWER INPUT, MIN. POWER INPUT (%)

The end points of the curve for the linear relationship are all that is required to describe the behavior of the system throughout its range. Power input values are expected at this time, and corresponding light output values with the next question.

- (if linear) LIGHT OUTPUT AT MAX POWER, LIGHT OUTPUT AT MIN POWER (%)

As described above, these values provide complete information for the linear curve. This information should be available from manufacturer's data.

- (if non-linear) INPUT THE NUMBER OF ORDERED PAIRS OF % POWER INPUT AND % LIGHT OUTPUT WHICH WILL BE USED TO DESCRIBE THE NON-LINEAR RELATIONSHIP

As was the case with stepped control, up to fifteen different sets of ordered pairs of power input and light output can be used, and the number of ordered pairs should be input here.

- (if non-linear) INPUT ORDERED PAIRS OF POWER INPUT AND LIGHT OUTPUT AVAILABLE: POWER (%), LIGHT (%)

It is from these ordered pairs of points that a curve is constructed, using linear interpolation between input points. The number of input pairs should be sufficient in number to reasonably describe the non-linear nature of the curve. A curve of this nature should by supplied by the control system manufacturer.

- MAXIMUM ARTIFICIAL ILLUMINANCE AVAILABLE (FC)

The space under consideration will have some lighting system layout, and depending on the type of equipment, density of luminaires, etc, the light level at full output will vary. This value should be calculated for the layout within the controlled space, and if sensor controls are involved, should correlate with the sensor location. It is assumed that this light level will be supplied initially under full power input and light output conditions, and will depreciate over time in accordance with specified year end maintenance factor values.

- MAXIMUM POWER AVAILABLE (WATTS/SQ. FT.)

To convert percentage power values to actual wattage values, this number is needed, and should be the wattage loading at full light output.

- DOES CONTROL SYSTEM UNDER ANALYSIS RESPOND TO DAYLIGHTING?

A <u>YES</u> or <u>NO</u> response will indicate whether the control system responds to natural illuminance in an Equi-Illuminance Dimming (EID) mode.

Note: If daylighting is present, the following information will be required.

- LONGITUDE OF SITE

The value of degrees longitude ranges from -180 to 180 and is necessary to convert from civil time to solar time when requesting calculated natural illuminance (E_n) values. All input times to the program are in civil time, but E_n values input are equally spaced around solar noon, with solar sunrise and solar sunset being set to zero within the program.

- NUMBER OF TIME ZONES WEST OF GREENWICH

This value also plays a part in converting from civil time to solar time when requesting daylighting input. A table of these values for the United States is included in the program user's guide.

- % CLEAR SKY PER MONTH

Daylighting curves for both clear and cloudy sky conditions can be analyzed in the program, and this value is used as a weighting function on a monthly basis. Separate calculations for total yearly energy consumptions are done for both clear and cloudy sky conditions, if present, and the percentage contribution to monthly energy consumption due to each of these conditions is determined with this value.

Percent clear sky information on a monthly basis are available from various sources for typical climates throughout the country.

- INPUT SKY CONDITIONS FOR DAYLIGHTING: CLEAR OR CLOUDY

As indicated, the word <u>CLEAR</u> or <u>CLOUDY</u> is expected here, and either condition can be input first. When all data is input for one condition, the program will prompt for similar data for the other condition.

- NUMBER OF VALUES OF NATURAL ILLUMIANCE TO INPUT FOR EACH DAY

When building a curve to describe how the values of daylighting vary over the course of a day, any odd number of points can be used as input to build the curve. Whatever number is specified must be used for all three days of analysis, March 21, June 21, and December 21, for either clear or cloudy conditions. The number of values of illuminance input to build the curves may be different for the clear and cloudy cases.

- HOUR OF SUNRISE IN CIVIL TIME, MARCH 21

Input the time of sunrise in civil time for this data. This value can be obtained from several sources for the site location in question.

- NATURAL ILLUMINANCE AT: (TIMES LISTED)

Calculated values of E_n at the times indicated should be input for the day in question. Daylighting calculations are not done by this program but, rather, are expected as input, and can be done via hand calculations, compute simulation or whatever method is deemed suitable. The values calculated must correlate to the location(s) of sensors within the space being controlled. An explanation of this requirement is more clearly explained in a discussion of program assumptions which appear in another portion of this report. This data is also required for June 21 and December 21 days, for both clear and cloudy sky conditions.

- HOUR OF SUNRISE IN CIVIL TIME, JUNE 21

Similar to information for March 21, and is also required for December 21. This data is only required to be given once, since either clear or cloudy sky conditions will share the same sunrise values.

(end of optional daylighting input)

- WILL SYSTEM BE MAINTAINED BEFORE THE END OF FIVE YEAR CYCLE?

Year-end maintenance factors for a full five year period can be input into the program to account for the depreciation over time of artificial illuminance. If some intermediate maintenance will be done on the system within the five year time span, the response should be YES, otherwise, the response should be NO.

- (if intermediate maintenance) HOW MANY TIMES?
  NOTE: CLEANING MUST OCCUR AT YEAR END

Up to four values of intermediate maintenance would be physically possible, although in a practical application it is doubtful whether there would ever be more than one occurrence of intermediate maintenance within the five year time span.

- (if intermediate maintenance) AT THE END OF WHAT YEAR(S) WILL THE SYSTEM BE MAINTAINED?

Indicate the year end for each time maintenance will be done as specified in the previous input.

- INPUT MAINTENANCE FACTOR AT YEAR END FOR: YR 1, YR 2, YR 3, YR 4, YR 5

A value, presumably less than 1.0, is to be input to indicate total system depreciation at the end of each year for the five year time span. If intermediate maintenance is specified, these values input should be the year end maintenance factor before year end maintenance takes place.

- (if intermediate maintenance) INPUT MAINTENANCE FACTOR AFTER INDICATED CLEANING AT END OF YEAR(S):

For those years when intermediate maintenance is to be done, a maintenance factor after cleaning occurs must be input. A graphical presentation of how these factors affect the maintenance curve is shown in the program user's guide.

Maintenance factor values specified should indicate total system depreciation due to lamp aging, dirt accumulation, etc. This type of information is readily available from the IES Handbook or some other reference source on lighting.

- NUMBER OF DAYS PER WEEK BUILDING LIGHTING SYSTEM IS UTILIZED

An interger number between one and seven is expected here, and the combination of all different control schemes and their days of operation should add up to this total value. If a building is not in operation on weekends, for instance, this value would be five.

- NUMBER OF DIFFERENT DAILY CONTROL SCHEMES USED

From one to seven different control schemes described by a unique E_C histogram and cost/kilowatt hour rate schedule can be input into the program. Each control scheme specified is assumed to occur on a weekly basis throughout the year.

For each separate control scheme, the following information is required:

- HOURS OF CONTROL SYSTEM OPERATION: START, STOP

Input start and stop times for each control system in decimal hours with values from 0.0 to 24.0. All time blocks with their respective E_C values must occur within these specified time limits.

- OVERALL CRITERION ILLUMINANCE LEVEL

The most commonly occurring value of E_C within the start and stop times can be input here, and any control blocks which differ from this will be specified separately.

- NUMBER OF DAYS OF THE WEEK CONTROL SCHEME IS IN OPERATION

This value is used as a weighting factor so that control schemes which occur more than one day per week need only be put in once. If a building was in operation seven days per week and had one control scheme in operation during the week and a different one on the weekend, the values of five and two respectively would be input for this question as each of these schemes is being described.

• INPUT TYPE OF CONTROL: TASK, OCCUPANCY OR LOAD

For convenience sake, an entire control scheme, or any part of that scheme, could be attributed to a response to one of these three factors. The input requirements are identical for TASK, OCCUPANCY or LOAD inputs, and these items can work in conjunction with each other. If a given time block is affected by more than one of these factors, the lastest input takes priority, and thus, task is overridden by occupancy, and occupancy by load.

Although the program will behave properly, however, the total E_C histogram is finally described, it does prove helpful if control scheme needs are thought of with respect to these three factors of task requirements, space occupancy scheduling, and load shedding demands, if they exist.

• NUMBER OF TIME BLOCKS WITH A SPECIFIC CRITERION ILLUMINANCE LEVEL FOR SPACE SCHEDULING CONTROL

Within any one control scheme day, each time block which has an E_C value different from that of the overall criterion illuminance value must be specified, and the number of those blocks should be indicated here.

• START TIME, STOP TIME AND CRITERION ILLUMINANCE FOR EACH BLOCK

For the number of time blocks indicated in the previous input, these values must be specified. The entire set of these blocks along with the overall value of E_C previously input thus constitute one complete control scheme day. All subsequent calculations for power needs and total energy usage for the controlled system are based upon this information.

• ENTER THE OVER COST/KWH (DOLLARS)

Similar in concept to the overall value of E_C, the most commonly occurring value of the cost of energy should be input here.

• ENTER THE NUMBER OF TIME BLOCKS WITH A DIFFERENT COST/KWH

Up to three different energy cost rates can be input at various times during the day to recognize an energy rate structure which may have off-peak, on-peak, or other variable costs throughout the day.

- ENTER START TIME, STOP TIME AND COST/KWH (DOLLARS) FOR EACH BLOCK

The format of this information is identical to that for specifying different values of E_C. It is not necessary that time blocks for different E_C values correlate with time blocks of different cost/KWH values. These two divisions can be treated independently by the user, and are combined within the program.

- COST TO DESIGN CONTROL SYSTEM (DOLLARS/SQ. FT.)

Often a forgotten item when considering the costs associated with implementing a control system is the design cost. Except for very simple systems, some analysis and design time will be needed and the owner will have to pay for these costs. This value, if present, should be expressed in dollars per square foot.

- COST OF CONTROL SYSTEM EQUIPMENT (DOLLARS/SQ, FT.)

For the total area being considered, all costs associated with the equipment for the control system should be input. This value should account only for the additional costs incurred because of the control system, and not include any costs which would be required whether the lighting system was controlled or not. As with system design costs, this value should be expressed in dollars per square foot.

- COST TO INSTALL CONTROL SYSTEM (DOLLARS/SQ. FT.)

Installation costs, on a dollar per square foot basis, which would occur due to having the control system, must be input and should reflect only those differential installation costs which would not occur if no control system was used.

- DIFFERENTIAL YEARLY MAINTENANCE COST OF CONTROL SYSTEM (DOLLARS/SQ. FT.)

An annual expense which relfects the difference in total maintenance costs between a controlled and non-controlled system. If it were the case that maintenance costs were lower with the controlled system than a non-controlled system, this value should be input as a negative amount.

- SALVAGE VALUE OF THE CONTROL SYSTEM AT THE END OF ITS ECONOMIC LIFE (DOLLARS)

If the control system has any cash value at the end of its useful life, that value can be indicated here. Often the salvage value amount is too small to affect the economic analysis. It is possible to have a negative dollar value here if, for example, it costs money to remove the system at the end of its economic life.

- ECONOMIC LIFE OF SYSTEM (YEARS)

This value should be an integer and serves as the time span for economic life cycle analysis. This could be the life of the control system hardware itself, or perhaps the economic life of the building it is in. Consideration should be given to the possibility of techinical advances in the field of lighting controls which may make the economic life of the system far shorter than its physical life.

- OVERALL INTEREST RATE

In any economic analysis, the cost of money should be considered, and the prevailing rate of interest for investments is this value.

POWER INPUT VS. LIGHT OUTPUT OPTIONS

Any one of three different power input vs. light output relationships can be used to express the characteristics of the lighting control system.

This data is usually expressed as a percentage, and to convert to actual power input and light output values, the total area of the controlled space, the maximum artificial footcandle level available and the watts per square foot loading to provide that footcandle level are required input. The three options available are: (1) discrete steps of power input and light output; (2) continuous dimming where power input vs. light output is a linear relationship; and (3) continuous dimming where power input vs. light output is a non-linear relationship.

Discrete Stepped Control

Up to 15 different ordered pairs ([%] power input, [%] light output) can be input to describe this relationship. If E_C for a time block does not match an input step, the next higher value of power input and corresponding light output will be used.

Continuous Dimming - Linear Relationship

The maximum and minimum values of the power input range and the corresponding light output at those values must be known. All values should be expressed in percent.

Continuous Dimming - Non-Linear Relationship

Up to 15 ordered pairs ([%] power input, [%] light output) can be used to build a curve which describes this relationship. The curve is formed by simple linear interpolation between input points.

Figure 1 shows a sample curve for each of these three options. The complete control system input which creates a curve representing the actual conditions is shown in Figure 2.

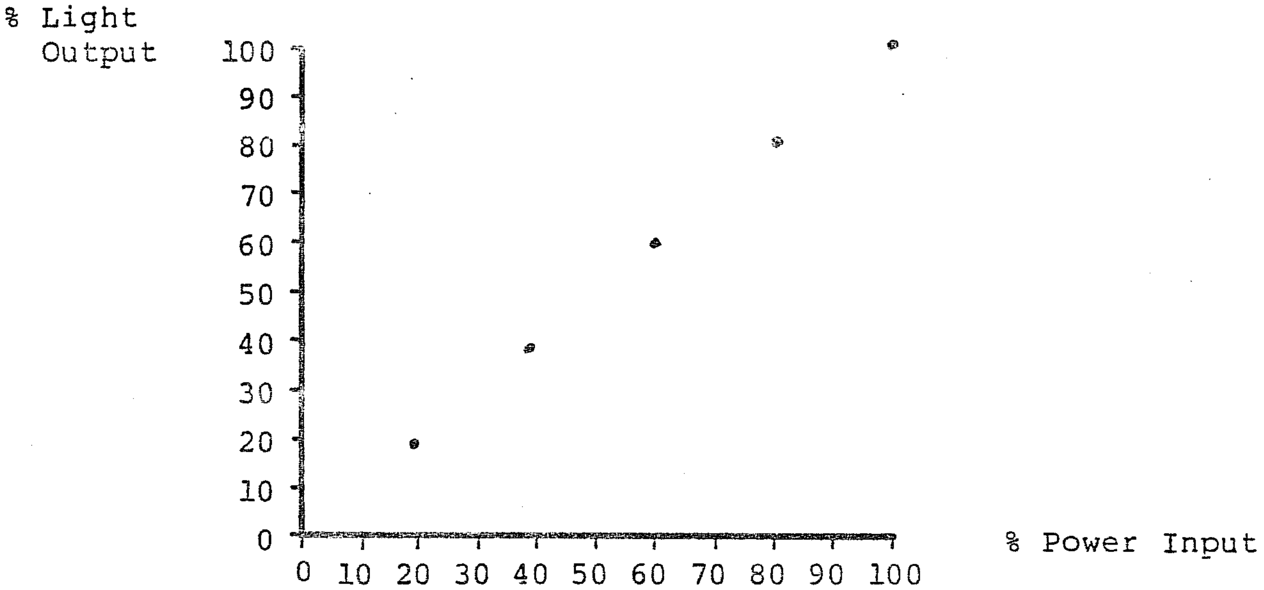


Fig. 1.a Discrete stepped relationship

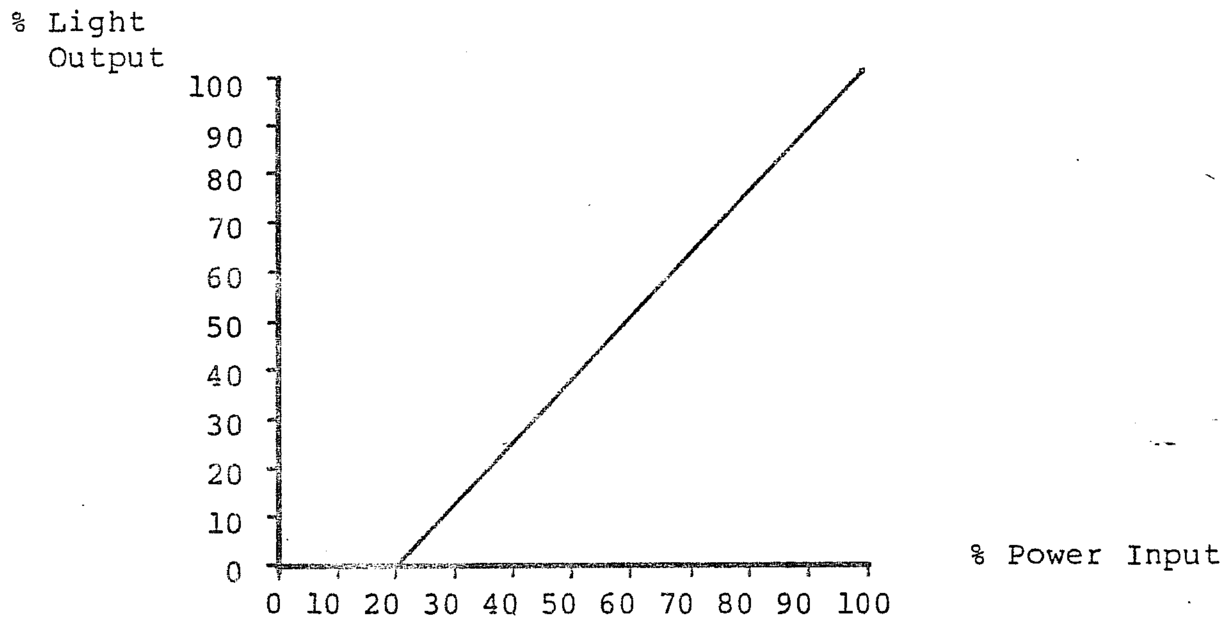


Fig. 1.b Continuous dimming, linear relationship

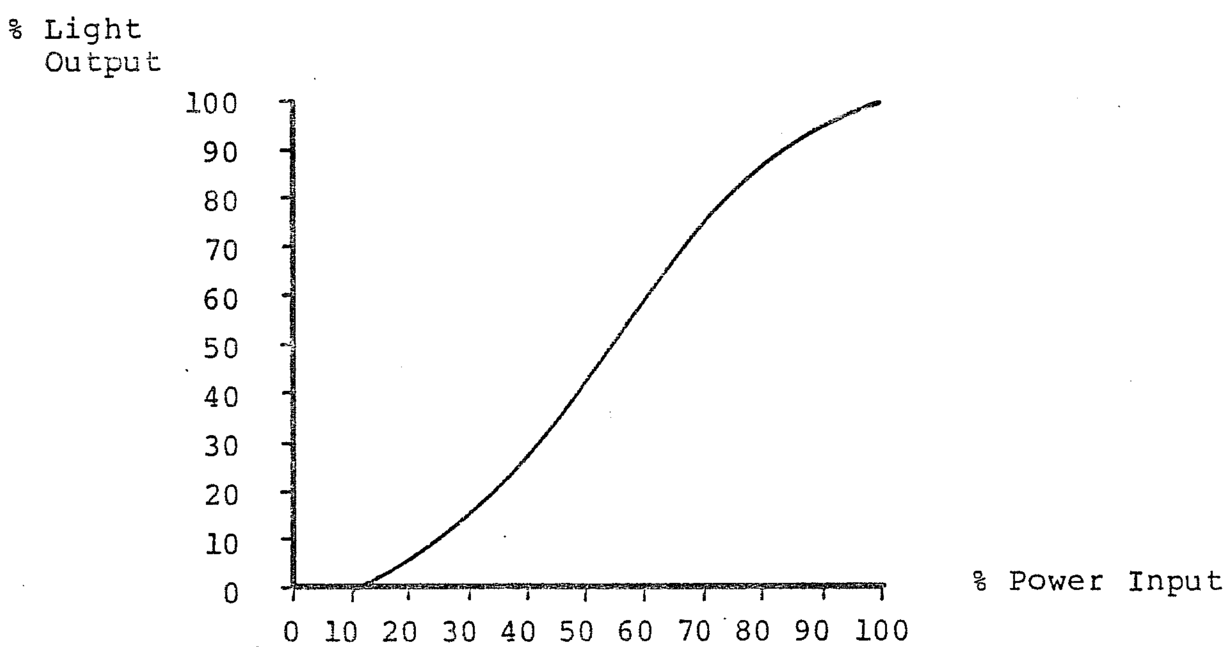


Fig. 1.c Continuous dimming, non-linear relationship

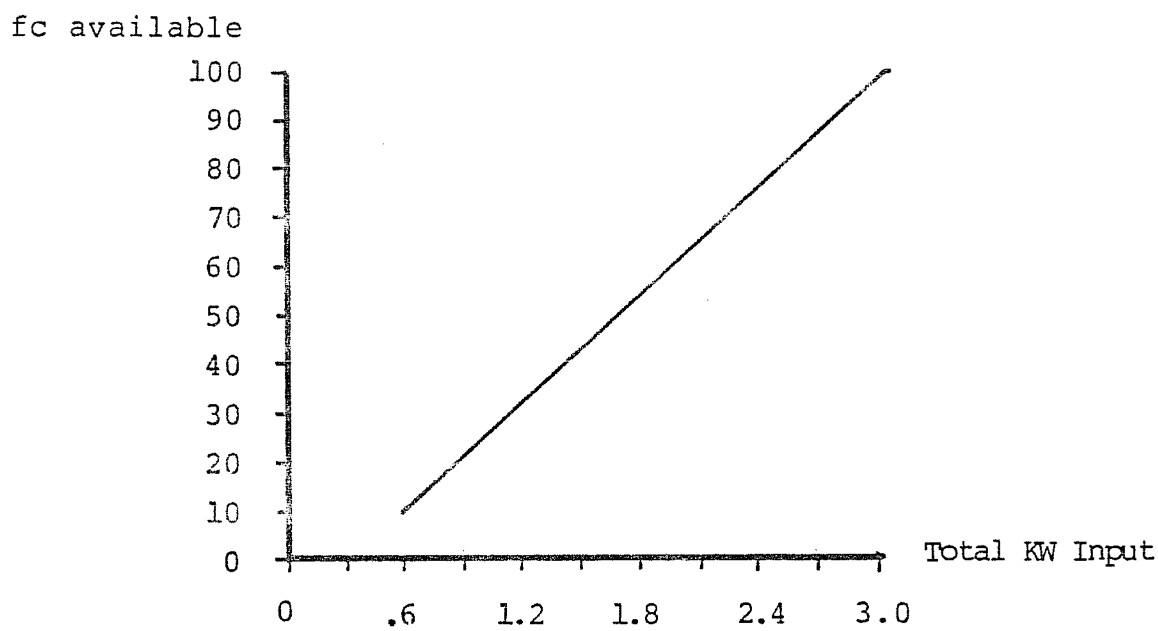


Fig. 2

Type of Control:	Continuous Dimming - Linear
Area in Square Feet:	1,000
Maximum Power Input:	100%
Maximum Power Input:	20%
Maximum Light Output:	100%
Minimum Light Output:	10%
Max. Artificial Footcandles:	100
Watts/Sq. Ft. at Maximum:	3.0

<u>Caution:</u> If an E_c value is specified which extends beyond the range that the control system is capable of providing, the program will not give accurate results.

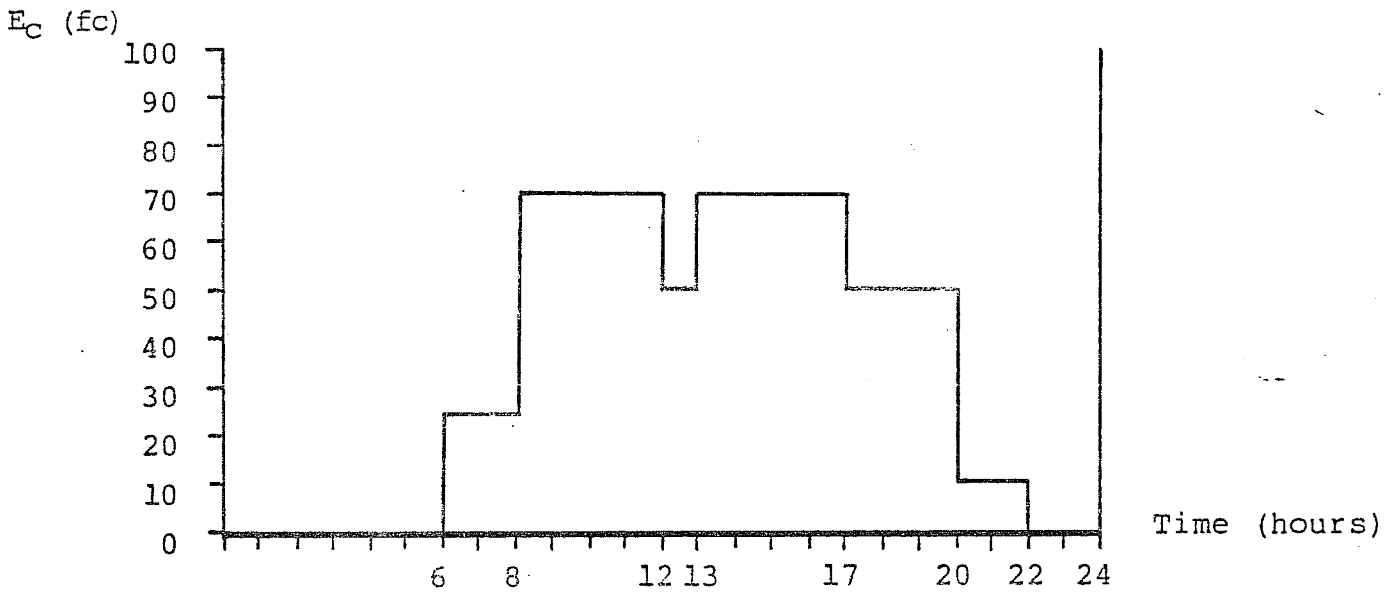


Fig. 3 Sample E_c histogram for a typical control day

The graph of Figure 3 could be thought of as an E_c histogram over the course of a typical day for a controlled lighting system. If there is no daylighting contribution into the space, the artificial lighting system alone will be controlled to provide the criteria illuminance levels specified for the time blocks shown. Compared against a baseline condition of full power input over the entire day, the resultant energy savings for the control scheme can be determined in a straightforward manner.

If the control system responds to daylighting in an equi-illumination dimming (EID) fashion, power consumption is a continuously varying quantity which is monitored over the hours of building operation.

Up to seven different daily control schemes can be described. It is assumed that the control scheme(s) input occur on a weekly basis throughout the entire year. The program is not set up to conveniently model an event such as having the system turned off for one week in December, for example, since yearly patterns are built up from day of the week control schemes which occur every week of the year.

A typical control system may occur five days of the week, with another pattern of control on weekends. This can be input conveniently by indicating the control scheme characteristics with a weighting factor for the number of days per week this particular scheme is in operation.

The baseline condition is the energy consumed over the hours of control system operation, from start to stop, with the system power input set to provide the maximum artificial illumination level for that entire time period.

Variations from the overall criterion illumination level can be input to respond to: (1) Task criteria; (2) Occupancy requirements; or (3) Load shedding. Start and stop times and the E_c for that time block or blocks are needed to describe this behavior. The relationship of these three options is best shown by the following simple example:

> Assume that the building is in operation from 6:00 a.m. to 6:00 p.m., with an overall criterion illumination level of 70 footcandles. This condition is represented by Figure 4.

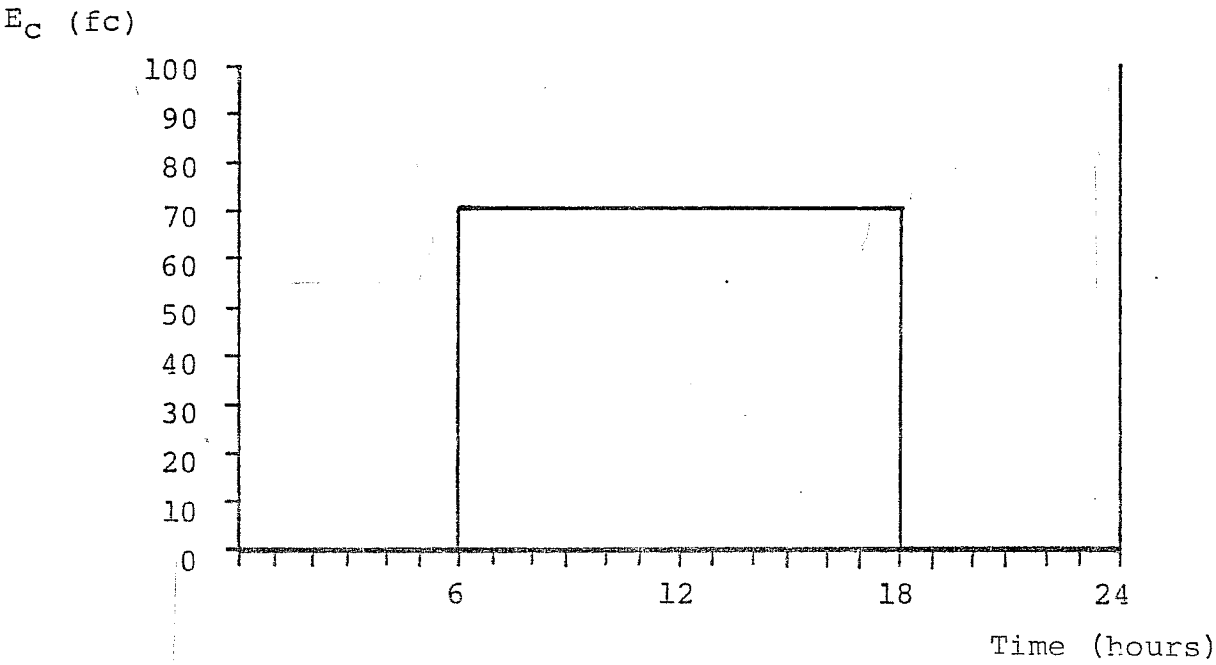


Fig. 4 General Overall Criterion of 70 fc from 6:00 a.m. to 6:00 p.m.

Task requirements are met by the overall criterion value in the morning, but the nature of the task requires an E_c of 90 footcandles from 1:00 p.m. to 5:00 p.m. This is shown in Figure 5.

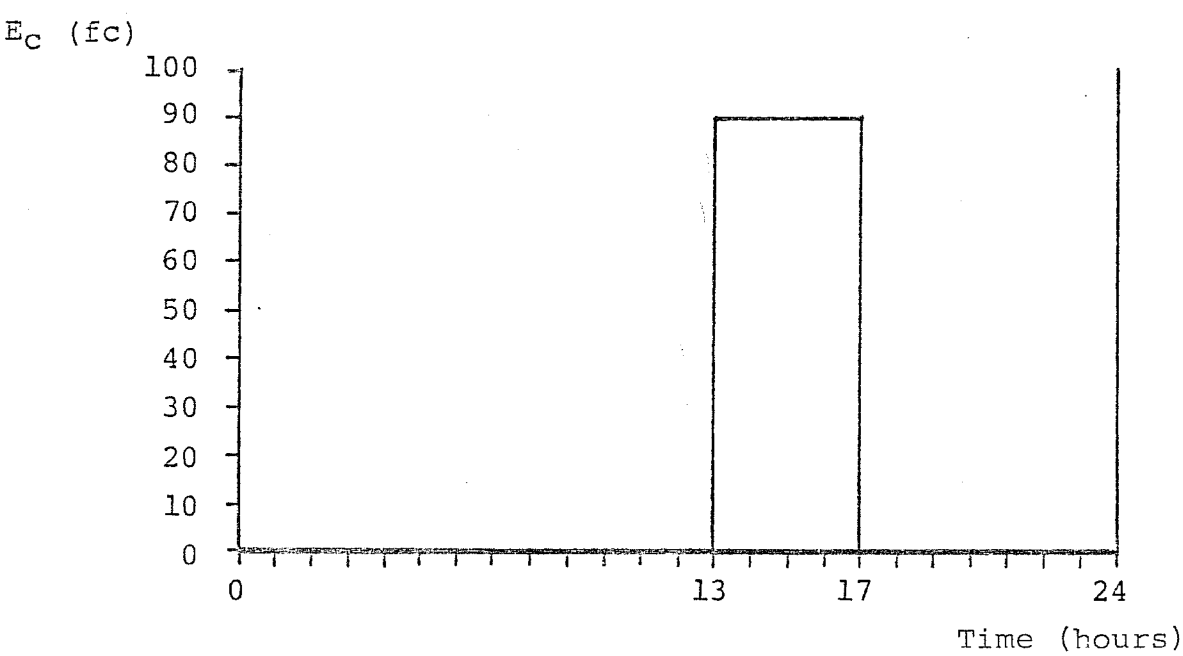


Fig. 5 E_c value of 90 footcandles from 1:00 p.m. until 5:00 p.m. to meet task requirements

Building occupancy patterns are such that from 6:00 a.m. to 7:30 a.m., 12:00 noon to 1:00 p.m., and from 5:30 p.m. to 6:00 p.m., a general light level of 35 footcandles is sufficient, as indicated by Figure 6.

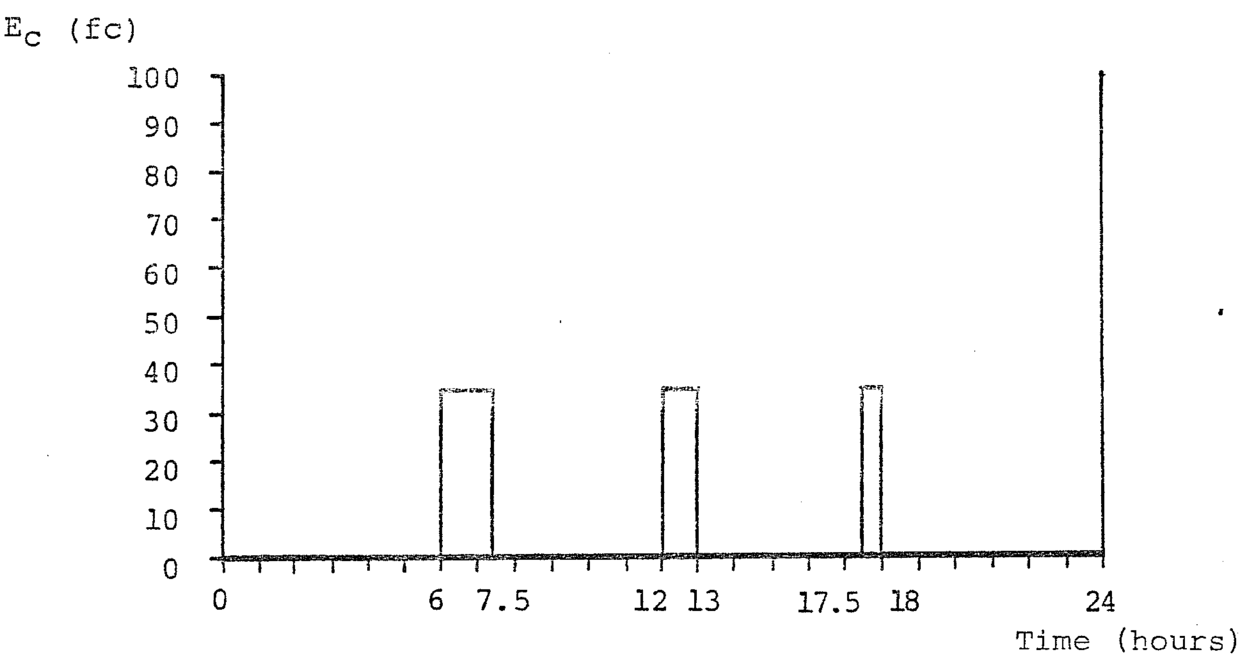


Fig. 6 E_c value of 35 footcandles at time blocks shown to meet building occupancy pattern

There is no load shedding control response for this space. Figure 7 shows the combined effect of this information and the resultant E_c histogram for this particular control scheme.

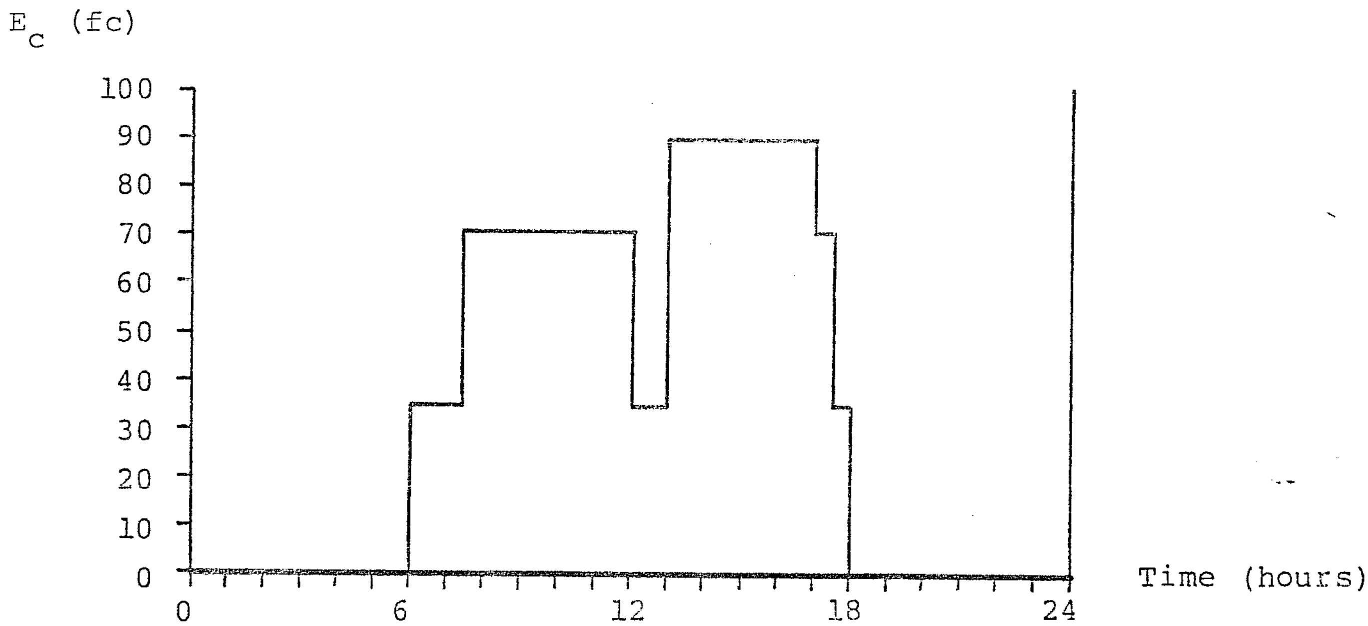


Fig. 7 Combined effect of overall E_c value with task and occupancy scheduling requirements

The options of task, occupancy, or load are prioritized as listed, with the last input E_c overriding previous ones if a time block is affected by more than one of these factors. The only exception to this is that if by some chance load shedding, to some level, say $E_c = 30$, caused the power input to increase to meet that E_c, that input is ignored. This is a guard against the remote condition when space occupancy or task requirements are already below some load shedding level which was to be accounted for during a given time block.

Note: All start and stop time blocks are to be specified in decimal hours from 0.00 to 24.00.

DAYLIGHTING RESPONSE

In some instances, a control system which monitors the available natural light, E_n, and alters the artificial light accordingly to maintain a specific E_c, proves to be the most cost effective control system. Such a system is often referred to as an Equi-Illumination Dimming system (EID). It is because of this type of system that this program was written, as the continuously varying light level available from daylighting does not lend itself to hand calculations. Non-daylighting systems which could be evaluated by hand can, of course, be handled easily by this program.

The mathematical model which formed the basis of this program is elaborated in a paper entitled "An Economic Analysis of Supplemental Skylighting for Industrial and Office Buildings", by S. Stannard, which appeared in the Journal of the Illuminating Engineering Society, July, 1979. The highlights of that model will be reviewed herein.

Daylighting Information for a Single Day

The curve expressing the available natural illuminance, E_n, at a lighting control sensor device over the course of a day is built by constructing a Fourier series from several known values of E_n at specific times of the day. The longitude of the site and the number of time zones west of Greenwich are needed to determine the solar sunrise time for the location. Table 1 lists time zones west of Greenwich for location in the United States. Solar sunrise and solar sunset assume $E_n = 0$, and input values of E_n are required at equally spaced times between these values. If three input data points are sufficient to describe the behavior of daylighting throughout the day, then E_n values at solar mid-morning, solar noon, and solar mid-afternoon must be known. The nature of the Fourier series used to fit data requires an odd number of input values, but any reasonable number can be used. See Figure 8.

TABLE 1

Time	Time Zone
Eastern Standard Time	5
Central Standard Time	6
Mountain Standard Time	7
Pacific Standard Time	8
Hawaiian Standard Time	10
Eastern Daylight Time	6
Central Daylight Time	7
Mountain Daylight Time	8
Pacific Daylight Time	9

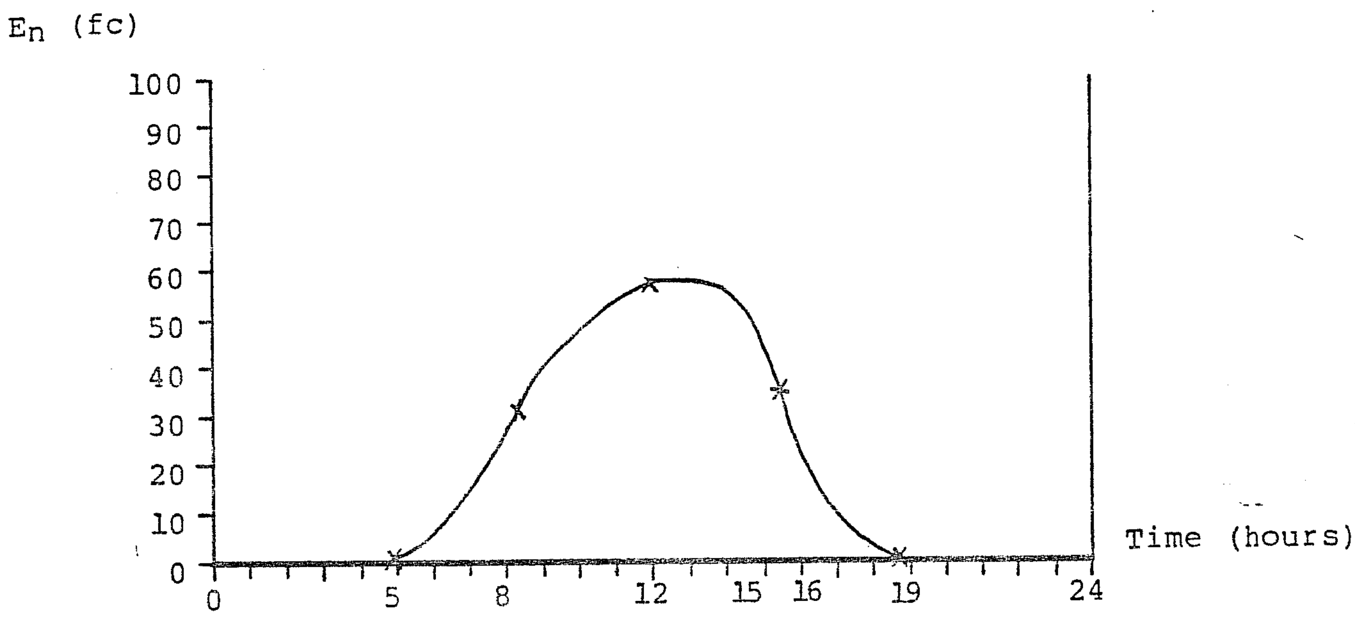


Fig. 8 Example of a curve of E_n built from 3 input points with solar sunrise and solar sunset defined to be zero

Appendix A discusses a "front end" computer program which determines at what time of the day daylighting must be calculated. This program can also interpolate at any time of the day the value of E_n which the Fourier series constructs. In this way, the user can test out the reasonableness of a small number of daylighting points in describing the behavior of available daylighting over the course of a day.

Daylighting Variations Over the Year

Fourier series curve fitting techniques are again used to model the yearly variations of the energy consumed by an EID system responding to daylighting. By inputting available E_n values over the course of a day, the total energy consumed by the system can be calculated for that day. Daylighting data on March 21, June 21, and December 21 result in total energy information data on these days of the year. September 21 data is equal to March 21 data, and thus, four points are available to building a curve of anticipated variations in total energy consumption throughout the year as that value is altered due to the system's responses to available daylight.

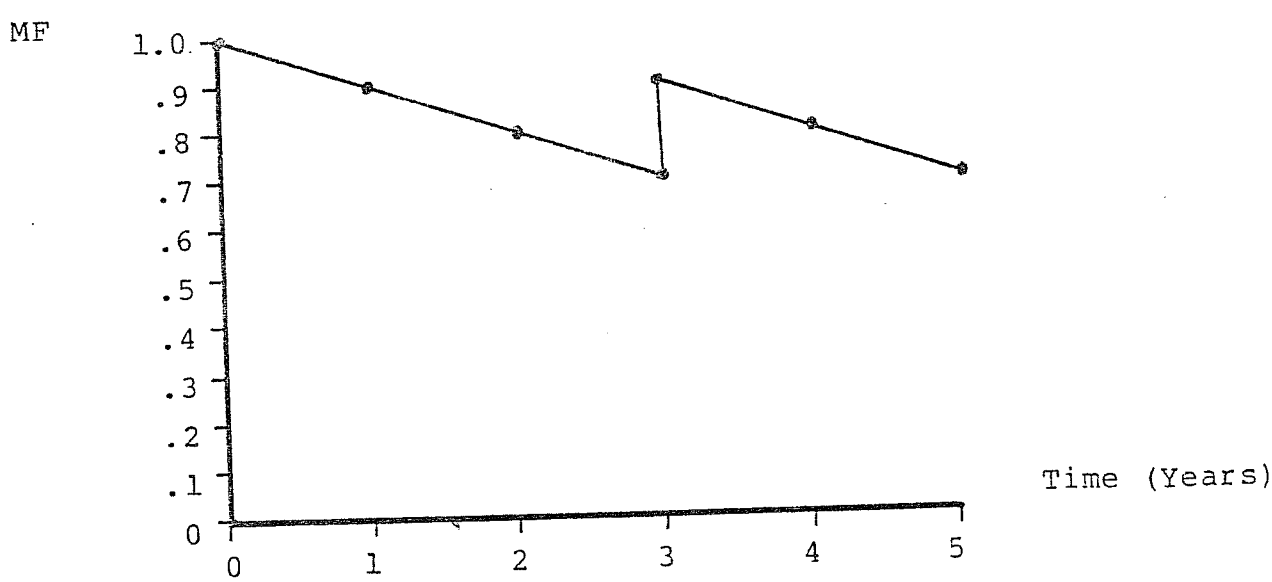
Daylighting calculation techniques for clear sky or cloudy sky conditions are well known, and both conditions can be accounted for in the program, if appropriate. An input parameter of % clear sky for each month of the year provides for a proper weighting factor of the energy savings resulting from clear or cloudy sky conditions.

The mathematical model discussed in Stannard's paper employed Fourier series integration techniques to determine the energy consumed throughout the day. That approach has been abandoned because of the complexity of it when discontinuities occur in the E_c histogram. A finite element approach has been used instead. Each time block with a specific E_c value is divided up into a large number of equal time increments. At the center of each time increment, the E_n curve is evaluated to get the available E_n at that time. Knowing the E_n available, and the E_c, the quantity of artificial light needed to maintain E_c is determined, and the resultant power to supply that light is calculated. Knowing the power needed and the length of the time increment, the energy required is then known. These values are added up along the time line from start to stop to get the total energy required for a given E_c histogram and corresponding daylight condition.

MAINTENANCE FACTORS

To maintain a specified E_C value as the artificial lighting level available decreases over time due to lamp and luminaire depreciation, more light and, consequently, more power will be required. In order to account for the resulting energy and cost increases, year-end maintenance factors (MF) for a five year period can be input. Linear interpolation between year end values gives the appropriate maintenance factor to be applied throughout the course of the year. If cleaning and/or relamping occur before the end of the five year period, adjusted maintenance factors can be input to reflect this. The beginning of the five year period is assumed to have a maintenance factor of 1.0.

Figure 9 indicates the maintenance factor curve over the five year period if the <u>year end</u> maintenance factors are as shown and intermediate maintenance at the end of the third year will bring the system back up to a MF = .90.



Year	MF at Year's End	
1	.9	
2	.8	
3	.7	(prior to intermediate maintenance)
4	.8	
5	.7	

Fig. 9 Five year maintenance factor curve for the year end values given

Maintenance factors are required input in all analysis modes except for the stepped control, non-daylight response mode. Practical usage of that type of control is typically not designed to change the power input and light output to meet a specified E_C level as the system depreciates over time.

ECONOMIC ANALYSIS

Before a control system can be said to be effective in saving energy, and ultimately dollars, it must be shown to be a good investment. There are numerous ways to analyze the economic performance of a particular system which requires a certain expenditure initially to save money in the future, and the well known techniques of Present Worth and Savings Investment Ratio are used here. These life cycle cost methods, and others, are discussed thoroughly in any of several books on engineering economy. The required input and the program output related to economic analysis can best be seen by referring to the examples at the end of the user's guide.

Cost/KWH Blocks

The operating cost of the lighting system, expressed in dollars/KWH, may vary over the course of a day. The realistic conditions of on-peak and off-peak energy costs can be input with up to four different cost blocks being specified. All subsequent economic analysis will account for these cost differences. The effect of rate structures can also be studied in their impact on the life cycle costs performance of one control scheme over another.

INPUT/OUTPUT CAPABILITIES

This program can be used either in the interactive time sharing mode or by reading from a stored data file. When operating in either mode, the user may elect to have his/her responses stored into a data file for future use, or have the output printed directly at the terminal.

An example of how these options are chosen when running the program is shown below:

```
IF DATA INPUT IS IN A DATA FILE, ENTER FILE NAME:
USERID/CATA/.../FILE
ELSE, LEAVE BLANK
=
IF YOU WISH YOUR RESPONSES TO BE SAVED INTO A FILE, ENTER FILE NAME
USERID/CATA/.../FILE
ELSE, LEAVE BLANK
=MCCLOSKEY/TYPICAL/INPUT
IF YOU WISH THE OUTPUT TO GO TO A FILE, ENTER FILE NAME.
USERID/CATA/.../FILE
ELSE, LEAVE BLANK
=MCCLOSKEY/TYPICAL/OUTPUT
```

If a file name is specified for input or output storage which does not exist, the program will create the file for the user. An empty file need not be created prior to running the program. An example of the terminal response in this situation is as follows:

```
IF YOU WISH YOUR RESPONSES TO BE SAVED INTO A FILE, ENTER FILE NAME
USERID/CATA/.../FILE
ELSE  LEAVE BLANK
=MCCLOSKEY/EX1IN
A FILE HAS BEEN CREATED NAMED:
MCCLOSKEY/EX1IN
IF YOU WISH THE OUTPUT TO GO TO A FILE, ENTER FILE NAME:
USERID/CATA/.../FILE
ELSE, LEAVE BLANK
=MCCLOSKEY/EX1OUT
A FILE HAS BEEN CREATED NAMED:
MCCLOSKEY/EX1OUT
```

JOBSTREAM FLOW

The list below indicates the required data needed to run the program. Data is listed in the order in which it must appear. For the sake of clarity, Table 1 lists each piece of data on a separate line, although data can be grouped in any convenient manner in the actual jobstream. An asterisk at the beginning of a line indicates that that data must start on a new line. Data indented is optional and may or may not be required, depending on previous information.

TABLE 1

* Character string(s) for output report heading (up to five lines)

* Area affected by control scheme (Sq. Ft.)

* Stepped or continuous dimmer control

(if stepped control)

  * No. of steps for power input vs. light output relationship

  * Ordered pairs of: ([%] power input, [%] light output)

(if continuous dimming)

  * Linear or non-linear continuous dimming

(if linear continuous dimming)

- * Maximum power input (%)
- Minimum power input (%)
- * Light output (%) at maximum power
- Light output (%) at minimum power

(if non-linear continous dimming)

- * No. of ordered pairs of power input vs. light output
- * Ordered pairs of: ([%] power input, [%] light output)

- * Maximum artificial illuminance (fc)
- * Watts/Sq. Foot load at maximum artificial illuminance
- * Control system response to daylighting (yes or no)

(if daylighting)

- * Longitude of site
- * Number of time zones west of Greenwich
- % Clear sky per month for:
  - * January, February, March
  - * April, May, June
  - * July, August, September
  - * October, November, December
- * Sky conditions - clear or cloudy
- * Number of input daylighting values
- * Hour of civil sunrise, March 21
- * Values of natural illuminance on March 21
- * Hour of civil sunrise, June 21
- * Values of natural illuminance on June 21
- * Hour of civil sunrise, December 21
- * Values of natural illuminance on December 21

(Values for other sky condition)

- * Number of daylighting input values
- * Values of natural illuminance on March 21
- * Values of natural illuminance on June 21
- * Values of natural illuminance on December 21

* System maintained before end of 5-year cycle (yes or no)
  - * How many times (Note: cleaning must occur at year end)
  - * At the end of what year(s) will the system be maintained
* Maintenance factors at year end: yr 1, yr 2, yr 3, yr 4, yr 5
  - * Maintenance factor after indicated cleaning at end of year(s):

* Number of days per week system is utilized
* Number of different daily control schemes

* Hours of control system operation: start, stop
* Overall criterion illumination level
* Number of days control scheme in operation
* Type of control: task, occupancy or load
* Number of time blocks with specific E_C
* Time block start time
  Time block stop time
  E_C for block

* Overall cost per kilowatt hour (dollars)
* Number of time blocks with cost differences
* Start time of cost block
  Stop time of cost block
  Cost/KWH (dollars) for time block

* Cost to design control system (dollars/sq.ft.)
* Cost of control system equipment (dollars/sq.ft.)
* Cost to install control system (dollars/sq.ft.)
* Differential annual maintenance cost of control system (dollars/sq.ft.)
* Salvage value of control system
* Economic life of system
* Overall interest rate (%)

Example 1

A single story, 12,000 square foot office building has a uniform lighting layout throughout the space producing an overall average of 75 footcandles at 2.4 watts/square foot. There are no individual switches for lights, and all lights are turned on at 7:00 a.m. when the first employee arrives and are left on until 11:00 p.m. after final maintenance work is done. The building will not be used on the weekends.

The power profile for a typical day is shown in Figure EX1.1.

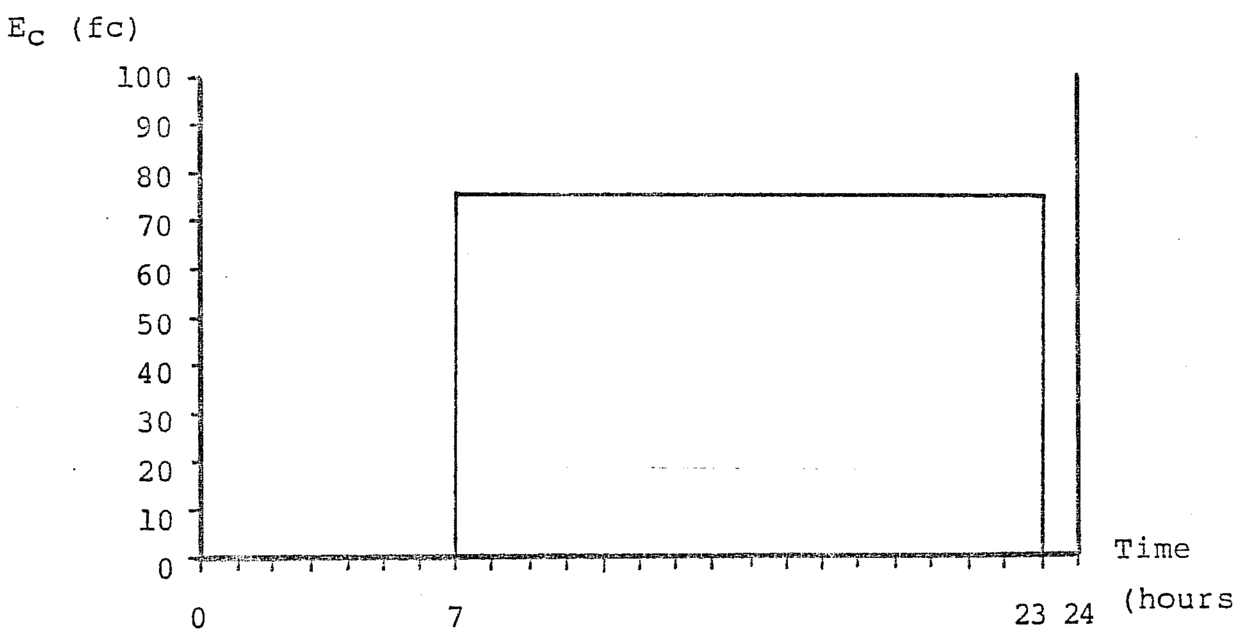


Figure EX1.1 Overall average of 75 footcandles with all lights turned on.

A control scheme utilizing three level switching, controlled by time clocks is proposed which would respond more realistically to building occupancy needs. Since the office tends to be open late on Fidays, two different power profiles are as shown in Figure EX1.2.

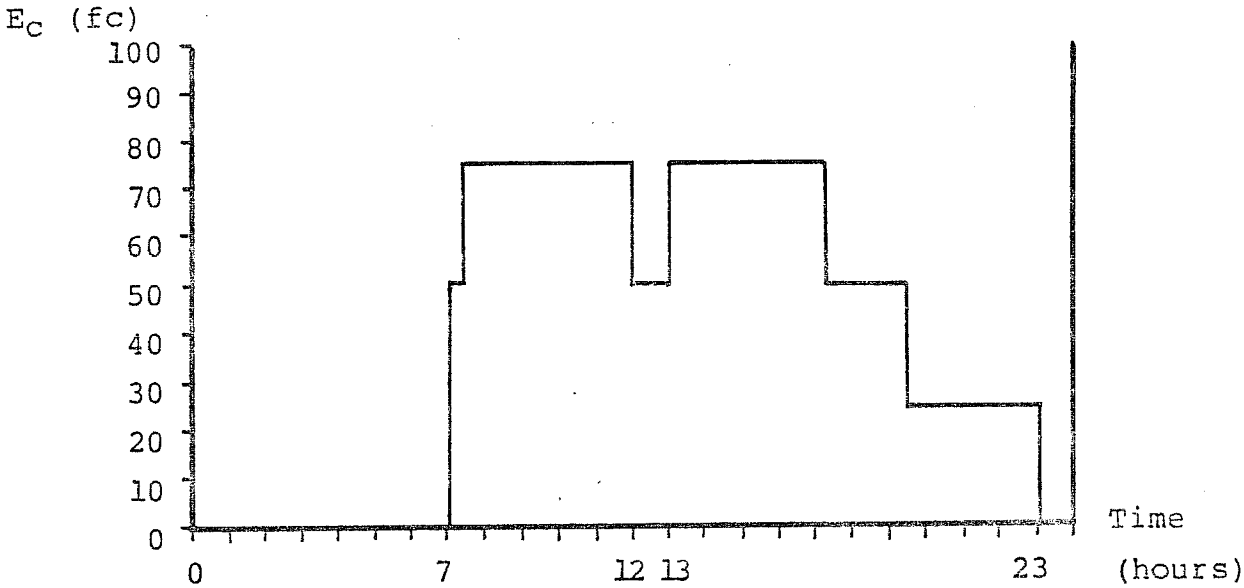


Figure EX1.2a E_c histogram for Monday thru Thursday schedule.

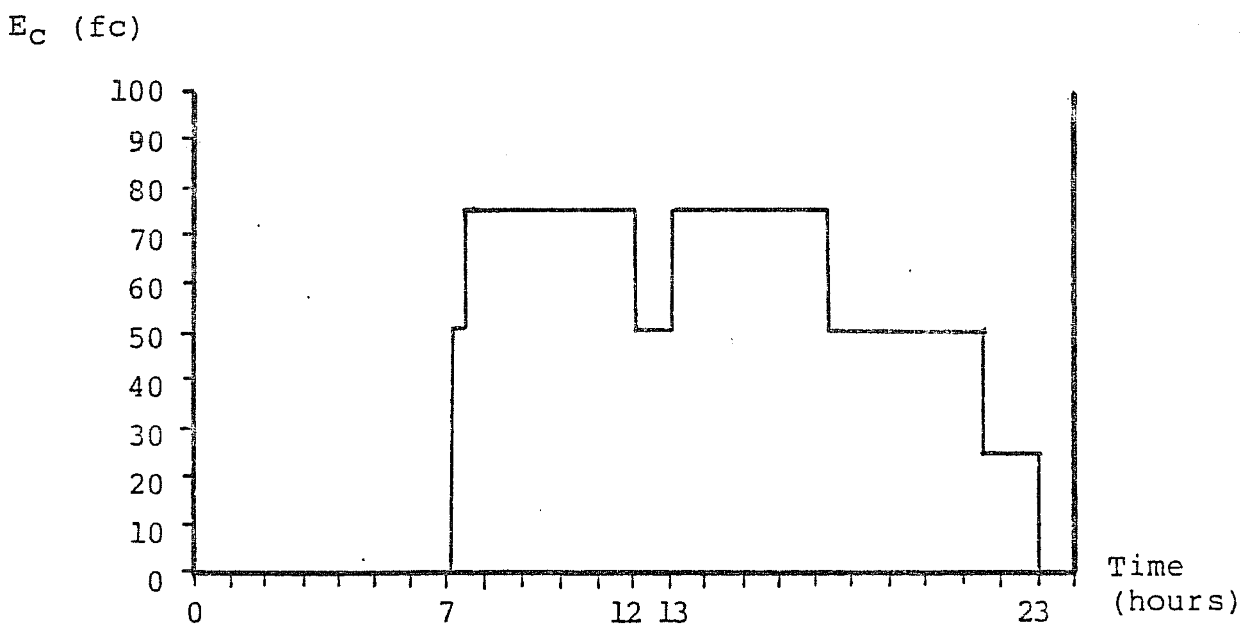


Figure EX1.2b E_c histogram for Friday occupancy schedule.

All luminaires are three lamp 2' x 4' recessed fluorescent troffers, and reductions in overall light levels will come from simply operating these units at one, two or three lamp output. Energy costs are at $.045/KWH, and control system equipment costs are for an installed system, thus, no separate installed costs.

```
IF DATA INPUT IS IN A DATA FILE, ENTER FILE NAME:
USERID/CATA/.../FILE
ELSE, LEAVE BLANK
=
IF YOU WISH YOUR RESPONSES TO BE SAVED INTO A FILE, ENTER FILE NAME:
USERID/CATA/.../FILE
ELSE, LEAVE BLANK
=/LBL/EX1IN
A FILE HAS BEEN CREATED NAMED:
/LBL/EX1IN
IF YOU WISH THE OUTPUT TO GO TO A FILE, ENTER FILE NAME:
USERID/CATA/.../FILE
ELSE, LEAVE BLANK
=/LBL/EX1OUT
A FILE HAS BEEN CREATED NAMED:
/LBL/EX1OUT


ENTER UP TO 5 LINES TO BE PRINTED AS A HEADING ON THE OUTPUT;
NO MORE THAN 80 CHARACTERS PER LINE
ENTER A BLANK LINE AT THE END IF LESS THAN 5 LINES
=EXAMPLE 1
=SIMPLE CONTROL SCHEME WITH STEPPED CONTROL
=NO DAYLIGHTING
=FILE: /LBL/EX1IN
=

AREA AFFECTED BY CONTROL SCHEME (SQ. FT.)?
=12000

WILL CONTROL SYSTEM UNDER CONSIDERATION BE
CONTINUOUS DIMMING OR STEPPED CONTROL?
=STEPPED
NUMBER OF DISCRETE STEPS FOR WHICH POWER INPUT
VS. LIGHT OUTPUT RELATIONSHIP IS KNOWN?
=3
INPUT 3 ORDERED PAIRS OF POWER INPUT AND
LIGHT OUTPUT: POWER(%), LIGHT(%)
=100,100
=67,67
=34,34
```

```
MAXIMUM ARTIFICIAL ILLUMINANCE AVAILABLE (FC)?
=75
MAXIMUM POWER AVAILABLE (WATTS/SQ.FT.)?
=2.4
DOES CONTROL SYSTEM UNDER ANALYSIS RESPOND TO DAYLIGHTING?
=NO

NUMBER OF DAYS PER WEEK BUILDING LIGHTING SYSTEM IS UTILIZED?
=5
NUMBER OF DIFFERENT DAILY CONTROL SCHEMES USED?
=2

                         FOR CONTROL SCHEME NUMBER 1

HOURS OF CONTROL SYSTEM OPERATION: START,STOP?
=7 23
OVERALL CRITERION ILLUMINATION LEVEL?
=75
NUMBER OF DAYS OF THE WEEK CONTROL SCHEME 1 IS IN OPERATION?
=4
INPUT TYPE OF CONTROL: TASK, OCCUPANCY OR LOAD
=OCCU
NUMBER OF TIME BLOCKS WITH A SPECIFIC CRITERION ILLUMINATION
LEVEL FOR SPACE OCCUPANCY SCHEDULING CONTROL?
=4
START TIME,STOP TIME AND CRITERION ILLUMINATION FOR EACH BLOCK?
=7 7.5 50
=12 13 50
=17.5 19.5 50
=19.5 23 25
INPUT TYPE OF CONTROL: TASK, OCCUPANCY OR LOAD
=
OVERALL COST/KWH(DOLLARS)?
=.045
NUMBER OF TIME BLOCKS WITH A DIFFERENT COST/KWH?
=0
```

FOR CONTROL SCHEME NUMBER 2

```
HOURS OF CONTROL SYSTEM OPERATION: START,STOP?
=7 23
OVERALL CRITERION ILLUMINATION LEVEL?
=75
NUMBER OF DAYS OF THE WEEK CONTROL SCHEME 2 IS IN OPERATION?
=1
INPUT TYPE OF CONTROL: TASK, OCCUPANCY OR LOAD
=OCCU
NUMBER OF TIME BLOCKS WITH A SPECIFIC CRITERION ILLUMINATION
LEVEL FOR SPACE OCCUPANCY SCHEDULING CONTROL?
=4
START TIME,STOP TIME AND CRITERION ILLUMINATION FOR EACH BLOCK?
=7   7.5 50
=12 13 50
=17.5 21.5 50
=21.5 23 25
INPUT TYPE OF CONTROL: TASK, OCCUPANCY OR LOAD
=
OVERALL COST/KWH(DOLLARS)?
=.045
NUMBER OF TIME BLOCKS WITH A DIFFERENT COST/KWH?
=0

CONTROL SYSTEM COST DATA:
COST TO DESIGN CONTROL SYSTEM(DOLLARS/SQ.FT.)?
=.025
COST OF CONTROL SYSTEM EQUIPMENT(DOLLARS/SQ.FT.)?
=.25
COST TO INSTALL CONTROL SYSTEM(DOLLARS/SQ.FT.)?
=0
DIFFERENTIAL YEARLY MAINTENANCE COST OF CONTROL SYSTEM(DOLLARS/SQ.FT.)?
=0
SALVAGE VALUE OF THE CONTROL SYSTEM
AT THE END OF ITS ECONOMIC LIFE(DOLLARS)?
=0
ECONOMIC LIFE OF SYSTEM(YEARS)?
=10
OVERALL INTEREST RATE(%)?
=15
```

EXAMPLE 1
SIMPLE CONTROL SCHEME WITH STEPPED CONTROL
NO DAYLIGHTING
FILE: /LBL/EX1IN

06/02/81

CONTROL SYSTEM CHARACTERISTICS

STEPPED CONTROL:	POWER(%)	LIGHT(%)
	34.0	34.0
	67.0	67.0
	100.0	100.0

AREA AFFECTED BY CONTROLS: 12000.00 SQ. FEET

MAXIMUM ARTIFICIAL ILLUMINANCE: 75.0 FOOTCANDLES
MAXIMUM POWER INPUT: 2.4 WATTS/SQ.FT.

BUILDING IS IN OPERATION 5 DAYS PER WEEK

FOR CONTROL SCHEME 1
****

CONTROL SCHEME STARTS AT 7.00 AND STOPS AT 23.00
IN EFFECT 4 DAYS PER WEEK

NET EFFECTIVE CONTROL BLOCKS SPECIFIED

START	STOP	CRITERION FC VALUE	COST/KWH
7.00	7.50	50.0	0.0450
7.50	12.00	75.0	0.0450
12.00	13.00	50.0	0.0450
13.00	17.50	75.0	0.0450
17.50	19.50	50.0	0.0450
19.50	23.00	25.0	0.0450

FOR CONTROL SCHEME 2
****

CONTROL SCHEME STARTS AT 7.00 AND STOPS AT 23.00
IN EFFECT 1 DAYS PER WEEK

NET EFFECTIVE CONTROL BLOCKS SPECIFIED

START	STOP	CRITERION FC VALUE	COST/KWH
7.00	7.50	50.0	0.0450
7.50	12.00	75.0	0.0450
12.00	13.00	50.0	0.0450
13.00	17.50	75.0	0.0450
17.50	21.50	50.0	0.0450
21.50	23.00	25.0	0.0450

ENERGY AND COST PERFORMANCE COMPARISON

FIRST COSTS FOR CONTROL SYSTEM

DESIGN COSTS: 300.00
EQUIPMENT COSTS: 3000.00
INSTALLATION COSTS: 0.

```
TOTAL DIFFERENTIAL MAINTENANCE COSTS/YEAR:          0.

CONTROL SYSTEM SALVAGE VALUE AT END OF LIFE:        0.

ECONOMIC LIFE OF SYSTEM:                        10.00
OVERALL INTEREST RATE:                          15.00

TOTAL KWH USED  FOR THE YEAR =          95111.07
TOTAL KWH SAVED FOR THE YEAR =          25026.07
TOTAL COST FOR THE YEAR=                 4280.00
TOTAL COST SAVED FOR THE YEAR=           1126.17
```

ANNUAL ENERGY COSTS

YEAR	BASE SYSTEM	CONTROLLED SYSTEM
1	5406.17	4280.00
2	5406.17	4280.00
3	5406.17	4280.00
4	5406.17	4280.00
5	5406.17	4280.00
6	5406.17	4280.00
7	5406.17	4280.00
8	5406.17	4280.00
9	5406.17	4280.00
10	5406.17	4280.00

TOTAL PRESENT WORTH(PW) COSTS AND
SAVINGS INVESTMENT RATIO (SIR) AT VARIOUS DIFFERENTIAL
ENERGY RATE INCREASES:

AT 0. % INCREASE/YEAR:

PW BASE:	27132.32
PW CONTROLLED:	24780.32
SIR	0.71

AT 3.0 % INCREASE/YEAR:

PW BASE:	30988.11
PW CONTROLLED:	27832.90
SIR	0.96

AT 6.0 % INCREASE/YEAR:

PW BASE:	35486.69
PW CONTROLLED:	31394.37
SIR	1.24

AT 9.0 % INCREASE/YEAR:

PW BASE:	40740.73
PW CONTROLLED:	35553.93
SIR	1.57

AT 12.0 % INCREASE/YEAR:

PW BASE:	46881.53
PW CONTROLLED:	40415.52
SIR	1.96

AT 15.0 % INCREASE/YEAR:

PW BASE:	54061.71
PW CONTROLLED:	46099.98
SIR	2.41

Example 2

A drafting area in a large commercial facility is to be a test installation for a new type of lighting control system. The system includes a retrofit fluorescent dimmer pack and a ceiling mounted photo cell. The purpose of the system is to maintain constant illumination in the space throughout its life. Initial power input and light output are below maximum values, and increase as lamp lumen depreciation and luminaire dirt depreciation occur. When the criteria illuminance value can no longer be supplied at full light output, cleaning and relamping will be done and the cycle starts over. (See Figure EX.2)

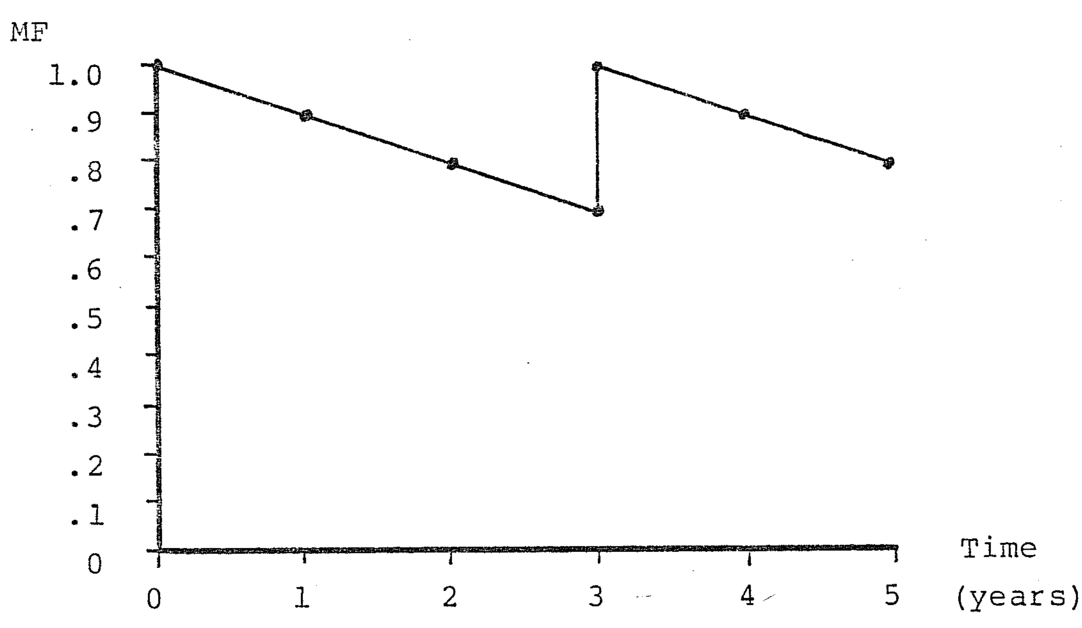


Figure EX.2 Graph of total light loss factor with a three year cleaning cycle.

The area is 1,000 square feet with a constant illuminance criteria of 110 footcandles. A three year cleaning cycle is in effect with depreciation down to 70% light output at the end of three years, thus, 160 footcandles initial must be provided. The watts per square foot loading is 4.2 watts per square foot. The power input vs. light output relationship is linear in the range of concern. No other special controls are planned, and the space is in operation 16 hours per day, 5 days of the week. The energy cost is .055 dollars/KWH.

```
IF DATA INPUT IS IN A DATA FILE, ENTER FILE NAME:
USERID/CATA/.../FILE
ELSE, LEAVE BLANK
=
IF YOU WISH YOUR RESPONSES TO BE SAVED INTO A FILE, ENTER FILE NAME:
USERID/CATA/.../FILE
ELSE, LEAVE BLANK
=/LBL/EX2AIN
A FILE HAS BEEN CREATED NAMED:
/LBL/EX2AIN
IF YOU WISH THE OUTPUT TO GO TO A FILE, ENTER FILE NAME:
USERID/CATA/.../FILE
ELSE, LEAVE BLANK
=/LBL/EX2AOUT
A FILE HAS BEEN CREATED NAMED:
/LBL/EX2AOUT


ENTER UP TO 5 LINES TO BE PRINTED AS A HEADING ON THE OUTPUT;
NO MORE THAN 80 CHARACTERS PER LINE
ENTER A BLANK LINE AT THE END IF LESS THAN 5 LINES
=EXAMPLE 2
=CONTINUOUS DIMMING - LINEAR RELATIONSHIP
=NO DAYLIGHTING
=FILE : /LBL/EX2AIN
=

AREA AFFECTED BY CONTROL SCHEME (SQ. FT.)?
=1000

WILL CONTROL SYSTEM UNDER CONSIDERATION BE
CONTINUOUS DIMMING OR STEPPED CONTROL?
=CONT
IS POWER INPUT VS. LIGHT OUTPUT A LINEAR OR NONLINEAR RELATIONSHIP?
=LIN
MAX. POWER INPUT, MIN. POWER INPUT (%)?
=100 40
LIGHT OUTPUT AT MAX. POWER, LIGHT OUTPUT AT MIN. POWER(%)?
```

```
=100 40
MAXIMUM ARTIFICIAL ILLUMINANCE AVAILABLE (FC)?
=160
MAXIMUM POWER AVAILABLE (WATTS/SQ.FT.)?
=4.2
DOES CONTROL SYSTEM UNDER ANALYSIS RESPOND TO DAYLIGHTING?
=NO

WILL SYSTEM BE MAINTAINED BEFORE THE END OF 5 YEAR CYCLE?
=YES
HOW MANY TIMES?    (NOTE: CLEANING MUST OCCUR AT YEAR END.)
=1
AT THE END OF WHAT YEAR(S) WILL THE SYSTEM BE MAINTAINED?
=3
INPUT MAINTENANCE FACTOR AT YEAR END FOR: YR1,YR2,YR3,YR4,YR5
(NOTE: BEFORE YEAR END MAINTENANCE IS DONE)
=.9 .8 .7 .9 .8
INPUT MAINTENANCE FACTOR AFTER INDICATED
CLEANING AT END OF YEAR(S):YR3
=1.0

NUMBER OF DAYS PER WEEK BUILDING LIGHTING SYSTEM IS UTILIZED?
=5
NUMBER OF DIFFERENT DAILY CONTROL SCHEMES USED?
=1

                         FOR CONTROL SCHEME NUMBER 1

HOURS OF CONTROL SYSTEM OPERATION: START,STOP?
=6 22
OVERALL CRITERION ILLUMINATION LEVEL?
=110
NUMBER OF DAYS OF THE WEEK CONTROL SCHEME 1 IS IN OPERATION?
=5
INPUT TYPE OF CONTROL: TASK, OCCUPANCY OR LOAD
=
OVERALL COST/KWH(DOLLARS)?
=.055
NUMBER OF TIME BLOCKS WITH A DIFFERENT COST/KWH?
=0
```

```
CONTROL SYSTEM COST DATA:
COST TO DESIGN CONTROL SYSTEM(DOLLARS/SQ.FT.)?
=0
COST OF CONTROL SYSTEM EQUIPMENT(DOLLARS/SQ.FT.)?
=.83
COST TO INSTALL CONTROL SYSTEM(DOLLARS/SQ.FT.)?
=.17
DIFFERENTIAL YEARLY MAINTENANCE COST OF CONTROL SYSTEM(DOLLARS/SQ.FT.)?
=0
SALVAGE VALUE OF THE CONTROL SYSTEM
AT THE END OF ITS ECONOMIC LIFE(DOLLARS)?
=0
ECONOMIC LIFE OF SYSTEM(YEARS)?
=12
OVERALL INTEREST RATE(%)?
=17
```

EXAMPLE 2
CONTINUOUS DIMMING - LINEAR RELATIONSHIP
NO DAYLIGHTING
FILE : /LBL/EX2AIN

06/04/81

------- ------ ---------------
CONTROL SYSTEM CHARACTERISTICS
------- ------ ---------------

CONTINUOUS DIMMING LINEAR RELATIONSHIP:	MAXIMUM POWER(%):	100.0
	MINIMUM POWER(%):	40.0
	MAXIMUM LIGHT(%):	100.0
	MINIMUM LIGHT(%):	40.0

AREA AFFECTED BY CONTROLS: 1000.00 SQ. FEET

MAXIMUM ARTIFICIAL ILLUMINANCE: 160.0 FOOTCANDLES
MAXIMUM POWER INPUT: 4.2 WATTS/SQ.FT.

	YEAR	MF
MAINTENANCE FACTORS AT YEAR END:		
	1	0.90
	2	0.80
	3	0.70
	4	0.90
	5	0.80
MAINTENANCE FACTOR FOLLOWING INTERMEDIATE CLEANING:	3	1.00

BUILDING IS IN OPERATION 5 DAYS PER WEEK

FOR CONTROL SCHEME 1
****

CONTROL SCHEME STARTS AT 6.00 AND STOPS AT 22.00
IN EFFECT 5 DAYS PER WEEK

NET EFFECTIVE CONTROL BLOCKS SPECIFIED

START	STOP	CRITERION FC VALUE	COST/KWH
6.00	22.00	110.0	0.0550

ENERGY AND COST PERFORMANCE COMPARISON

YEAR	KWH USED	KWH SAVED
1	12714.17	4805.83
2	14219.79	3300.21
3	16131.70	1388.30
4	12714.17	4805.83
5	14219.79	3300.21

FIRST COSTS FOR CONTROL SYSTEM

DESIGN COSTS:	0.
EQUIPMENT COSTS:	830.00
INSTALLATION COSTS:	170.00

TOTAL DIFFERENTIAL MAINTENANCE COSTS/YEAR: 0.

CONTROL SYSTEM SALVAGE VALUE AT END OF LIFE: 0.

ECONOMIC LIFE OF SYSTEM: 12.00
OVERALL INTEREST RATE: 17.00

ANNUAL ENERGY COSTS

YEAR	BASE SYSTEM	CONTROLLED SYSTEM
1	963.60	699.28
2	963.60	782.09
3	963.60	887.24
4	963.60	699.28
5	963.60	782.09
6	963.60	887.24
7	963.60	699.28
8	963.60	782.09
9	963.60	887.24
10	963.60	699.28
11	963.60	782.09
12	963.60	887.24

TOTAL PRESENT WORTH(PW) COSTS AND
SAVINGS INVESTMENT RATIO (SIR) AT VARIOUS DIFFERENTIAL
ENERGY RATE INCREASES:

AT 0. % INCREASE/YEAR:

PW BASE:	4806.81
PW CONTROLLED:	4889.80
SIR	-0.08

AT 3.0 % INCREASE/YEAR:

PW BASE:	5553.23
PW CONTROLLED:	5504.33
SIR	0.05

AT 6.0 % INCREASE/YEAR:

PW BASE:	6446.05
PW CONTROLLED:	6240.41
SIR	0.21

AT 9.0 % INCREASE/YEAR:

PW BASE:	7517.01
PW CONTROLLED:	7124.61
SIR	0.39

AT 12.0 % INCREASE/YEAR:

PW BASE:	8804.64
PW CONTROLLED:	8189.21
SIR	0.62

AT 15.0 % INCREASE/YEAR:

PW BASE:	10355.59
PW CONTROLLED:	9473.37
SIR	0.88

Example 3

A fluorescent Equi-Illumination Dimming System which responds to daylight input as well as light loss variations is being considered for the perimeter zone of a large open office area. Criterion illuminance of 60 footcandle on the desk is desired and the total maintenance factor will be 80 footcandles minimum at the end of a three year cleaning cycle; thus 75 initial footcandles must be provided by the artificial lighting system for times when daylight is not available. A total area of 1400 square feet loaded at 1.8 Watt per square foot is to be controlled by the same sensor. The power input vs light output relationship is slightly non-linear, as shown in Figure EX. 3.1. The lighting system operates from 6:00 a.m. to 6:00 p.m. five days per week. The off-peak energy rate is .048 dollars/kwh and on-peak rate is .064 dollars/kwh between the hours of 9:00 a.m. and 1:00 p.m. Three input values of daylight available in the space are sufficient to describe the variation in daylight throughout the day, for both clear and cloudy conditions. Daylight values, % clear sky and all other input paramaters are included below in the listing of the interactive terminal session.

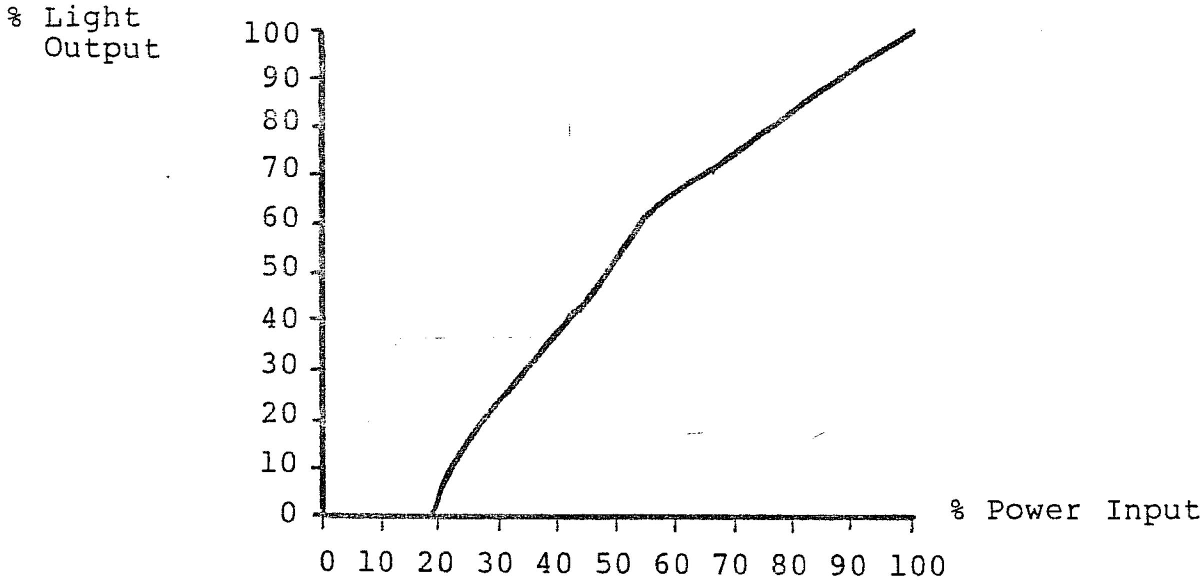


FIG. EX. 3.1. Non-linear relationship for flourescent diming equipment

```
IF DATA INPUT IS IN A DATA FILE, ENTER FILE NAME:
USERID/CATA/.../FILE
ELSE, LEAVE BLANK
=
IF YOU WISH YOUR RESPONSES TO BE SAVED INTO A FILE, ENTER FILE NAME:
USERID/CATA/.../FILE
ELSE, LEAVE BLANK
=/LBL/EX3IN
A FILE HAS BEEN CREATED NAMED:
/LBL/EX3IN
IF YOU WISH THE OUTPUT TO GO TO A FILE, ENTER FILE NAME:
USERID/CATA/.../FILE
ELSE, LEAVE BLANK
=/LBL/EX3OUT
A FILE HAS BEEN CREATED NAMED:
/LBL/EX3OUT


ENTER UP TO 5 LINES TO BE PRINTED AS A HEADING ON THE OUTPUT;
NO MORE THAN 80 CHARACTERS PER LINE
ENTER A BLANK LINE AT THE END IF LESS THAN 5 LINES
=EXAMPLE 3
=CONTINUOUS DIMMING NON-LINEAR RELATIONSHIP
=DAYLIGHTING PRESENT
=FILE : /LBL/EX3IN
=

AREA AFFECTED BY CONTROL SCHEME (SQ. FT.)?
=1400

WILL CONTROL SYSTEM UNDER CONSIDERATION BE
CONTINUOUS DIMMING OR STEPPED CONTROL?
=CONT
IS POWER INPUT VS. LIGHT OUTPUT A LINEAR OR NONLINEAR RELATIONSHIP?
=NON
INPUT THE NUMBER OF ORDERED PAIRS OF % POWER INPUT AND % LIGHT OUTPUT
WHICH WILL BE USED TO DESCRIBE THE NON-LINEAR RELATIONSHIP.
=11
```

```
INPUT 11 ORDERED PAIRS OF POWER INPUT AND
LIGHT OUTPUT: POWER(%), LIGHT(%)
=18 0
=23 10
=28 20
=35 30
=42 40
=47 50
=54 60
=66 70
=77 80
=88 90
=100 100
MAXIMUM ARTIFICIAL ILLUMINANCE AVAILABLE (FC)?
=75
MAXIMUM POWER AVAILABLE (WATTS/SQ.FT.)?
=1.8
DOES CONTROL SYSTEM UNDER ANALYSIS RESPOND TO DAYLIGHTING?
=YES
LONGITUDE OF SITE?
=82
NUMBER OF TIME ZONES WEST OF GREENWICH?
=5
% CLEAR SKY PER MONTH:
JAN FEB MAR
=30 30 35
APL MAY JUN
=50 55 60
JLY AUG SEP
=60 55 50
OCT NOV DEC
=50 45 40
INPUT SKY CONDITION FOR DAYLIGHTING INFORMATION: CLEAR OR CLOUDY
=CLEAR
```

DAYLIGHTING INFORMATION UNDER CLEAR SKY CONDITIONS

```
NUMBER OF VALUES OF NATURAL ILLUMINANCE TO INPUT FOR EACH DAY
=3
HOUR OF LOCAL SUNRISE, MR21
=6.7
NATURAL ILLUMINANCE AT:     9.2    11.7    14.1
=60 85 110
HOUR OF LOCAL SUNRISE, JN21
=6.2
NATURAL ILLUMINANCE AT:     8.9    11.6    14.2
=80 95 130
HOUR OF LOCAL SUNRISE, DC21
=76
=7.6
NATURAL ILLUMINANCE AT:     9.5    11.5    13.4
=45 70 90
```

DAYLIGHTING INFORMATION UNDER CLOUDY SKY CONDITIONS

```
NUMBER OF VALUES OF NATURAL ILLUMINANCE TO INPUT FOR EACH DAY
=3
FOR  MR21
NATURAL ILLUMINANCE AT:     9.2    11.7    14.1
=30 40 45
FOR  JN21
NATURAL ILLUMINANCE AT:     8.9    11.6    14.2
=40 45 60
FOR  DC21
NATURAL ILLUMINANCE AT:     9.5    11.5    13.4
=25 35 40

WILL SYSTEM BE MAINTAINED BEFORE THE END OF 5 YEAR CYCLE?
=YES
HOW MANY TIMES?    (NOTE: CLEANING MUST OCCUR AT YEAR END.)
=1
AT THE END OF WHAT YEAR(S) WILL THE SYSTEM BE MAINTAINED?
=3
```

```
INPUT MAINTENANCE FACTOR AT YEAR END FOR: YR1,YR2,YR3,YR4,YR5
(NOTE: BEFORE YEAR END MAINTENANCE IS DONE)
=.92 .87 .80 .92 .87
INPUT MAINTENANCE FACTOR AFTER INDICATED
CLEANING AT END OF YEAR(S):YR3
=1.0

NUMBER OF DAYS PER WEEK BUILDING LIGHTING SYSTEM IS UTILIZED?
=5
NUMBER OF DIFFERENT DAILY CONTROL SCHEMES USED?
=1

                         FOR CONTROL SCHEME NUMBER 1

HOURS OF CONTROL SYSTEM OPERATION: START,STOP?
=6 18
OVERALL CRITERION ILLUMINATION LEVEL?
=60
NUMBER OF DAYS OF THE WEEK CONTROL SCHEME 1 IS IN OPERATION?
=5
INPUT TYPE OF CONTROL: TASK, OCCUPANCY OR LOAD
=
OVERALL COST/KWH(DOLLARS)?
=.048
NUMBER OF TIME BLOCKS WITH A DIFFERENT COST/KWH?
=1
START TIME,STOP TIME AND COST/KWH (DOLLARS) FOR EACH BLOCK?
=9 13 .064

CONTROL SYSTEM COST DATA:
COST TO DESIGN CONTROL SYSTEM(DOLLARS/SQ.FT.)?
=.12
COST OF CONTROL SYSTEM EQUIPMENT(DOLLARS/SQ.FT.)?
=1.05
COST TO INSTALL CONTROL SYSTEM(DOLLARS/SQ.FT.)?
=.30
DIFFERENTIAL YEARLY MAINTENANCE COST OF CONTROL SYSTEM(DOLLARS/SQ.FT.)?
=0
```

```
SALVAGE VALUE OF THE CONTROL SYSTEM
AT THE END OF ITS ECONOMIC LIFE(DOLLARS)?
=0
ECONOMIC LIFE OF SYSTEM(YEARS)?
=15
OVERALL INTEREST RATE(%)?
=15
```

EXAMPLE 3
CONTINUOUS DIMMING NON-LINEAR RELATIONSHIP
DAYLIGHTING PRESENT
FILE : /LBL/EX3IN

06/08/81

CONTROL SYSTEM CHARACTERISTICS

CONTINUOUS DIMMING
NON-LINEAR RELATIONSHIP:

POWER(%)	LIGHT(%)
18.0	0.
23.0	10.0
28.0	20.0
35.0	30.0
42.0	40.0
47.0	50.0
54.0	60.0
66.0	70.0
77.0	80.0
88.0	90.0
100.0	100.0

AREA AFFECTED BY CONTROLS: 1400.00 SQ. FEET

MAXIMUM ARTIFICIAL ILLUMINANCE: 75.0 FOOTCANDLES
MAXIMUM POWER INPUT: 1.8 WATTS/SQ.FT.

MAINTENANCE FACTORS
AT YEAR END:

YEAR	MF
1	0.92
2	0.87
3	0.80
4	0.92
5	0.87

MAINTENANCE FACTOR
FOLLOWING INTERMEDIATE
CLEANING: 3 1.00

BUILDING IS IN OPERATION 5 DAYS PER WEEK

FOR CONTROL SCHEME 1
****

CONTROL SCHEME STARTS AT 6.00 AND STOPS AT 18.00
IN EFFECT 5 DAYS PER WEEK

NET EFFECTIVE CONTROL BLOCKS SPECIFIED

START	STOP	CRITERION FC VALUE	COST/KWH
6.00	9.00	60.0	0.0480
9.00	13.00	60.0	0.0640
13.00	18.00	60.0	0.0480

DAYLIGHTING INFORMATION

LONGITUDE OF SITE: 82.0

TIME ZONES WEST OF GREENWICH: 5

	MARCH 21	JUNE 21	DEC 21
LOCAL SUNRISE:	6.7	6.2	7.6

INPUT TIMES AND LIGHTING LEVELS: CLEAR SKY CONDITIONS

TIME	FC	TIME	FC	TIME	FC
9.2	60.0	8.9	80.0	9.5	45.0
11.7	85.0	11.6	95.0	11.5	70.0
14.1	110.0	14.2	130.0	13.4	90.0

INPUT TIMES AND LIGHTING LEVELS: CLOUDY SKY CONDITIONS

TIME	FC	TIME	FC	TIME	FC
9.2	30.0	8.9	40.0	9.5	25.0
11.7	40.0	11.6	45.0	11.5	35.0
14.1	45.0	14.2	60.0	13.4	40.0

ENERGY AND COST PERFORMANCE COMPARISON

MONTHLY VARIATIONS FOR YEAR 1
****

MONTH	%CL	%CD	KWHUSED	KWHSAVED	COST	SAVINGS
JAN	30.	70.	528.95	140.65	27.14	8.58
FEB	30.	70.	434.11	170.69	22.34	9.92
MAR	35.	65.	416.72	252.88	21.50	14.21
APL	50.	50.	342.81	305.19	17.67	16.89
MAY	55.	45.	334.34	335.26	17.23	18.49
JUN	60.	40.	318.90	329.10	16.41	18.15
JLY	60.	40.	328.93	340.67	16.93	18.78

AUG	55.	45.	339.56	330.04	17.50	18.22
SEP	50.	50.	363.09	284.91	18.70	15.86
OCT	50.	50.	430.98	238.62	22.11	13.60
NOV	45.	55.	481.65	166.35	24.65	9.91
DEC	40.	60.	534.34	135.26	27.33	8.38

TOTAL KWH USED= 4854.39
TOTAL KWH SAVED= 3029.61

MONTHLY VARIATIONS FOR YEAR 2
****

JAN	30.	70.	558.68	110.92	28.62	7.10
FEB	30.	70.	460.37	144.43	23.65	8.61
MAR	35.	65.	443.09	226.51	22.82	12.89
APL	50.	50.	362.99	285.01	18.68	15.88
MAY	55.	45.	351.43	318.17	18.07	17.64
JUN	60.	40.	333.54	314.46	17.14	17.42
JLY	60.	40.	344.67	324.93	17.71	18.00
AUG	55.	45.	358.37	311.23	18.43	17.28
SEP	50.	50.	385.30	262.70	19.80	14.76
OCT	50.	50.	456.95	212.65	23.40	12.32
NOV	45.	55.	508.99	139.01	26.00	8.56
DEC	40.	60.	563.48	106.12	28.77	6.94

TOTAL KWH USED= 5127.86
TOTAL KWH SAVED= 2756.14

MONTHLY VARIATIONS FOR YEAR 3
****

JAN	30.	70.	608.25	61.35	31.09	4.63
FEB	30.	70.	495.15	109.65	25.38	6.87
MAR	35.	65.	469.50	200.10	24.13	11.58
APL	50.	50.	380.96	267.04	19.56	15.00
MAY	55.	45.	370.04	299.56	18.99	16.72
JUN	60.	40.	352.92	295.08	18.09	16.47
JLY	60.	40.	363.76	305.84	18.65	17.06
AUG	55.	45.	376.05	293.55	19.30	16.41
SEP	50.	50.	405.63	242.37	20.80	13.76
OCT	50.	50.	487.79	181.81	24.92	10.79
NOV	45.	55.	551.74	96.26	28.12	6.44
DEC	40.	60.	615.39	54.21	31.35	4.36

TOTAL KWH USED= 5477.17
TOTAL KWH SAVED= 2406.83

MONTHLY VARIATIONS FOR YEAR 4
****

JAN	30.	70.	528.95	140.65	27.14	8.58
FEB	30.	70.	434.11	170.69	22.34	9.92
MAR	35.	65.	416.72	252.88	21.50	14.21
APL	50.	50.	342.81	305.19	17.67	16.89
MAY	55.	45.	334.34	335.26	17.23	18.49
JUN	60.	40.	318.90	329.10	16.41	18.15
JLY	60.	40.	328.93	340.67	16.93	18.78
AUG	55.	45.	339.56	330.04	17.50	18.22
SEP	50.	50.	363.09	284.91	18.70	15.86
OCT	50.	50.	430.98	238.62	22.11	13.60
NOV	45.	55.	481.65	166.35	24.65	9.91
DEC	40.	60.	534.34	135.26	27.33	8.38

TOTAL KWH USED= 4854.39
TOTAL KWH SAVED= 3029.61

MONTHLY VARIATIONS FOR YEAR 5
****

JAN	30.	70.	558.68	110.92	28.62	7.10
FEB	30.	70.	460.37	144.43	23.65	8.61
MAR	35.	65.	443.09	226.51	22.82	12.89
APL	50.	50.	362.99	285.01	18.68	15.88
MAY	55.	45.	351.43	318.17	18.07	17.64
JUN	60.	40.	333.54	314.46	17.14	17.42
JLY	60.	40.	344.67	324.93	17.71	18.00
AUG	55.	45.	358.37	311.23	18.43	17.28
SEP	50.	50.	385.30	262.70	19.80	14.76
OCT	50.	50.	456.95	212.65	23.40	12.32
NOV	45.	55.	508.99	139.01	26.00	8.56
DEC	40.	60.	563.48	106.12	28.77	6.94

TOTAL KWH USED= 5127.86
TOTAL KWH SAVED= 2756.14

FIRST COSTS FOR CONTROL SYSTEM

DESIGN COSTS:	168.00
EQUIPMENT COSTS:	1470.00
INSTALLATION COSTS:	420.00

TOTAL DIFFERENTIAL MAINTENANCE COSTS/YEAR: 0.

CONTROL SYSTEM SALVAGE VALUE AT END OF LIFE: 0.

ECONOMIC LIFE OF SYSTEM 15.00

OVERALL INTEREST RATE: 15.00

ANNUAL ENERGY COSTS

YEAR	BASE SYSTEM	CONTROLLED SYSTEM
1	420.48	249.50
2	420.48	263.07
3	420.48	280.40
4	420.48	249.50
5	420.48	263.07
6	420.48	280.40
7	420.48	249.50
8	420.48	263.07
9	420.48	280.40
10	420.48	249.50
11	420.48	263.07
12	420.48	280.40
13	420.48	249.50
14	420.48	263.07
15	420.48	280.40

TOTAL PRESENT WORTH(PW) COSTS AND
SAVINGS INVESTMENT RATIO (SIR) AT VARIOUS DIFFERENTIAL
ENERGY RATE INCREASES:

AT 0. % INCREASE/YEAR:

PW BASE:	2458.70
PW CONTROLLED:	3595.22
SIR	-0.55

AT 3.0 % INCREASE/YEAR:

PW BASE:	2918.10
PW CONTROLLED:	3884.53
SIR	-0.47

AT 6.0 % INCREASE/YEAR:

PW BASE:	3493.74
PW CONTROLLED:	4247.28
SIR	-0.37

AT 9.0 % INCREASE/YEAR:

PW BASE:	4219.32
PW CONTROLLED:	4704.82
SIR	-0.24

AT 12.0 % INCREASE/YEAR:

PW BASE:	5138.38
PW CONTROLLED:	5284.77
SIR	-0.07

AT 15.0 % INCREASE/YEAR:

PW BASE:	6307.20
PW CONTROLLED:	6022.83
SIR	0.14

III FOURIER SERIES CURVE-FIT VALIDATION

When a lighting control system which responds to daylighting is to be analyzed, daylight calculations must be done to supply input to the program. In an attempt to minimize the number of input points required, Fourier series curve fitting is used to generate a complete curve from a small number of equally spaced input points. Whether the curve generated closely matches actual conditions over the course of a day has a significant impact on how closely the computer program will predict actual system energy savings.

Included are comparisons between actual measurements and the Fourier series curve generated from a small number of input points for two different daylighting conditions. Both sets of data were taken on June 28, 1980 at the Pacific Gas & Electric building in San Francisco. As can be seen from Figures 1 and 2, the Fourier series curve built from five input points closely matched measured conditions, and the curve generated from only three input points also does a reasonable job for most of the points.

P.G.E. ZONE 3
SOUTHWEST FACING
JUNE 28, 1980
CLEAR DAY - DRAPES CLOSED

Civilian Daylight-Savings Time	Illuminance On Ceiling (LUX)	Civilian Daylight-Savings Time	Illuminance On Ceiling (LUX)
8:00	17.8	4:00	123.3
15	19.3	15	128.5
30	20.1	30	127.7
45	19.5	45	128
9:00	20.9	5:00	127.7
15	21.4	15	127.5
30	-	30	-
45	22.9	45	127.6
10:00	22.5	6:00	118.4
15	21.3	15	106.5
30	20.0	30	93
45	22.4	45	58.7
11:00	21.3	7:00	9.9
15	-	15	10.9
30	20.1	30	10.2
45	19.5	45	0
12:00	17.8	8:00	0
15	17.5	15	0
30	-	30	- 1.4
45	20.6	45	2.3
1:00	22.9	9:00	- 1.4
15	24.5	15	1.6
30	-	30	0.8
45	33.3		
2:00	40.9		
15	49.2		
30	-		
45	70.9		
3:00	84.7		
15	96.5		
30	-		
45	-		

```
DO YOU WISH TO CHECK INTERMEDIATE TIMES OF
THE DAY TO SEE IF THE POINTS YOU INPUT WILL
GENERATE REASONABLE ILLUMINANCE VALUES FOR THOSE TIMES?
=YES
INPUT THE NUMBER OF DAYLIGHTING CALCULATIONS
WHICH YOU HOPE TO INPUT TO EXPRESS THE DAYLIGHTING
EFFECTS FOR A DAY.(AN ODD NUMBER)
=3 <--
LONGITUDE OF SITE
=122
NUMBER OF TIME ZONES WEST OF GREENWICH
=9
HOUR OF LOCAL SUNRISE, JN21
=5.83
NATURAL ILLUMINANCE CALCULATED AT:  9.36 12.89 16.42
=21.4 22.9 12.7
HOW MANY INTERPOLATED POINTS DO YOU WISH TO CHECK?
=35
INPUT TIME OF DAY FOR INTERPOLATION CHECK
=6
INTERPOLATED ILLUMINANCE VALUE IS:  3.07
=6.5
INTERPOLATED ILLUMINANCE VALUE IS: 11.72
=7
INTERPOLATED ILLUMINANCE VALUE IS: 19.06
=7.5
INTERPOLATED ILLUMINANCE VALUE IS: 24.31
=8
INTERPOLATED ILLUMINANCE VALUE IS: 26.96
=8.5
INTERPOLATED ILLUMINANCE VALUE IS: 26.90
=9
INTERPOLATED ILLUMINANCE VALUE IS: 24.38
=9.5
INTERPOLATED ILLUMINANCE VALUE IS: 20.05
=10
INTERPOLATED ILLUMINANCE VALUE IS: 14.86
=10.5
INTERPOLATED ILLUMINANCE VALUE IS:  9.94
```

```
=11
INTERPOLATED ILLUMINANCE VALUE IS:  6.51
=11.5
INTERPOLATED ILLUMINANCE VALUE IS:  5.68
=12
INTERPOLATED ILLUMINANCE VALUE IS:  8.31
=12.5
INTERPOLATED ILLUMINANCE VALUE IS: 14.93
=13
INTERPOLATED ILLUMINANCE VALUE IS: 25.59
=13.5
INTERPOLATED ILLUMINANCE VALUE IS: 39.84
=14
INTERPOLATED ILLUMINANCE VALUE IS: 56.77
=14.5
INTERPOLATED ILLUMINANCE VALUE IS: 75.04
=15
INTERPOLATED ILLUMINANCE VALUE IS: 93.00
=15.5
INTERPOLATED ILLUMINANCE VALUE IS:108.89
=16
INTERPOLATED ILLUMINANCE VALUE IS:120.96
=16.5
INTERPOLATED ILLUMINANCE VALUE IS:127.67
=17
INTERPOLATED ILLUMINANCE VALUE IS:127.86
=17.5
INTERPOLATED ILLUMINANCE VALUE IS:120.87
=18
INTERPOLATED ILLUMINANCE VALUE IS:106.65
=18.5
INTERPOLATED ILLUMINANCE VALUE IS: 85.75
=19
INTERPOLATED ILLUMINANCE VALUE IS: 59.30
=19.5
INTERPOLATED ILLUMINANCE VALUE IS: 28.95
=20
INTERPOLATED ILLUMINANCE VALUE IS: -3.34
=20.5
INTERPOLATED ILLUMINANCE VALUE IS:-35.40
```

```
DO YOU WISH TO CHECK INTERMEDIATE TIMES OF
THE DAY TO SEE IF THE POINTS YOU INPUT WILL
GENERATE REASONABLE ILLUMINANCE VALUES FOR THOSE TIMES?
=YES
INPUT THE NUMBER OF DAYLIGHTING CALCULATIONS
WHICH YOU HOPE TO INPUT TO EXPRESS THE DAYLIGHTING
EFFECTS FOR A DAY.(AN ODD NUMBER)
=5 <---
LONGITUDE OF SITE
=122
NUMBER OF TIME ZONES WEST OF GREENWICH
=9
HOUR OF LOCAL SUNRISE, JN21
=5.83
NATURAL ILLUMINANCE CALCULATED AT:  8.18 10.54 12.89 15.24 17.60
=19.3 20 22.9           96.5 127
HOW MANY INTERPOLATED POINTS DO YOU WISH TO CHECK?
=30
INPUT TIME OF DAY FOR INTERPOLATION CHECK
=6
INTERPOLATED ILLUMINANCE VALUE IS:  1.46
=6.5
INTERPOLATED ILLUMINANCE VALUE IS:  5.77
=7
INTERPOLATED ILLUMINANCE VALUE IS: 10.07
=7.5
INTERPOLATED ILLUMINANCE VALUE IS: 14.26
=8
INTERPOLATED ILLUMINANCE VALUE IS: 18.07
=8.5
INTERPOLATED ILLUMINANCE VALUE IS: 21.12
=9
INTERPOLATED ILLUMINANCE VALUE IS: 23.01
=9.5
INTERPOLATED ILLUMINANCE VALUE IS: 23.44
=10
INTERPOLATED ILLUMINANCE VALUE IS: 22.39
=10.5
INTERPOLATED ILLUMINANCE VALUE IS: 20.19
```

```
=11
INTERPOLATED ILLUMINANCE VALUE IS: 17.54
=11.5
INTERPOLATED ILLUMINANCE VALUE IS: 15.51
=12
INTERPOLATED ILLUMINANCE VALUE IS: 15.29
=12.5
INTERPOLATED ILLUMINANCE VALUE IS: 18.08
=13
INTERPOLATED ILLUMINANCE VALUE IS: 24.74
=13.5
INTERPOLATED ILLUMINANCE VALUE IS: 35.64
=14
INTERPOLATED ILLUMINANCE VALUE IS: 50.49
=14.5
INTERPOLATED ILLUMINANCE VALUE IS: 68.28
=15
INTERPOLATED ILLUMINANCE VALUE IS: 87.38
=15.5
INTERPOLATED ILLUMINANCE VALUE IS:105.70
=16
INTERPOLATED ILLUMINANCE VALUE IS:120.97
=16.5
INTERPOLATED ILLUMINANCE VALUE IS:131.01
=17
INTERPOLATED ILLUMINANCE VALUE IS:134.06
=17.5
INTERPOLATED ILLUMINANCE VALUE IS:128.95
=18
INTERPOLATED ILLUMINANCE VALUE IS:115.33
=18.5
INTERPOLATED ILLUMINANCE VALUE IS: 93.66
=19
INTERPOLATED ILLUMINANCE VALUE IS: 65.22
=19.5
INTERPOLATED ILLUMINANCE VALUE IS: 31.96
=20
INTERPOLATED ILLUMINANCE VALUE IS: -3.69
=20.5
INTERPOLATED ILLUMINANCE VALUE IS:-39.06
```

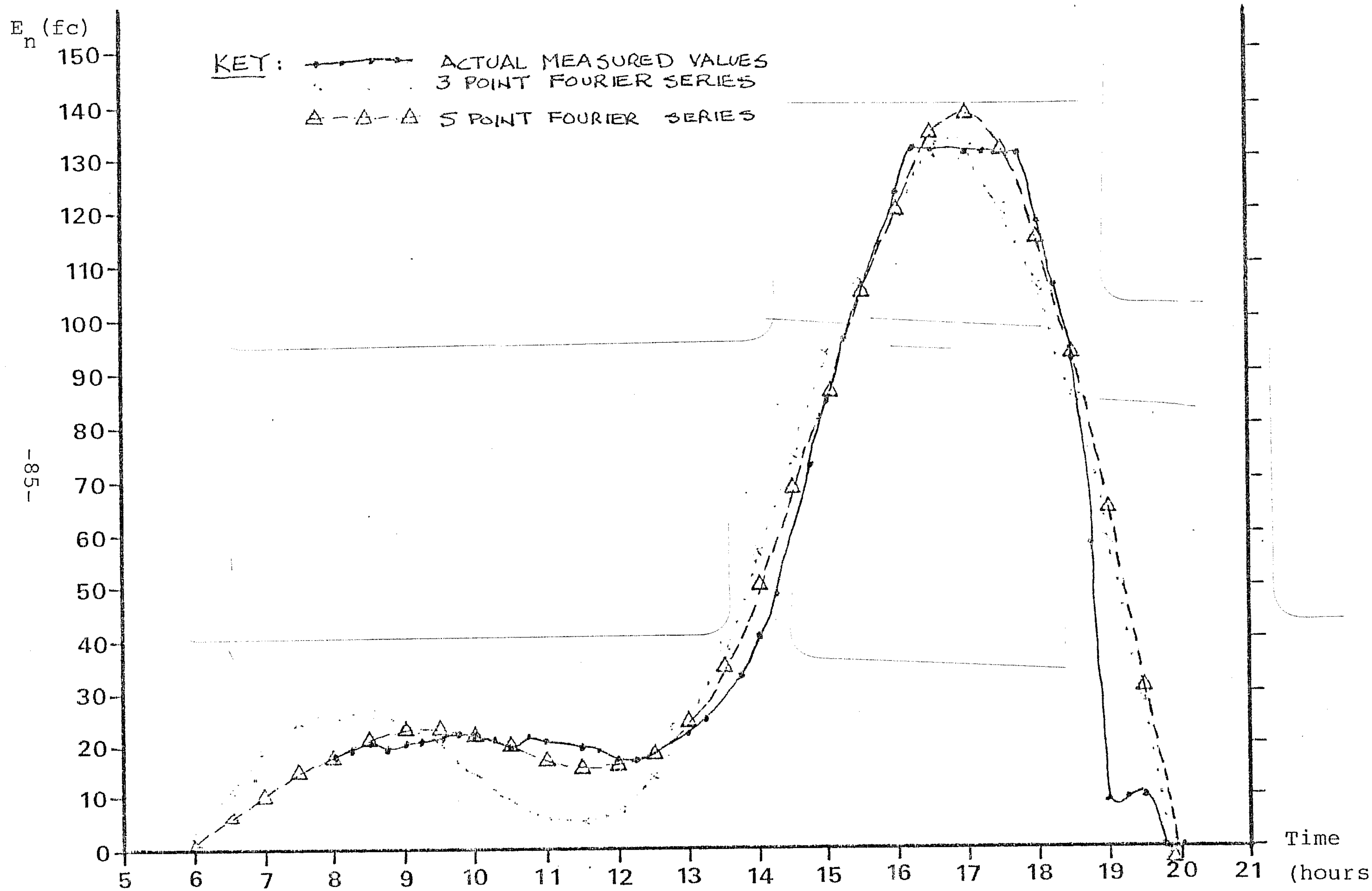


Fig. 1 Comparison of actual measured values vs. Fourier series curve generated from 3 and 5 input points. Measured points taken from P.G.& E. zone 3, southwest facing, drapes closed, clear day on June 28, 1980.

P.G.E. ZONE 4
SOUTHEAST FACING
JUNE 28, 1980
CLEAR DAY - DRAPES CLOSED

Civilian Daylight-Savings Time	Illuminance On Ceiling (LUX)	Civilian Daylight-Savings Time	Illuminance On Ceiling (LUX)
8:00	82.1	4:00	40.5
15	97.9	15	41.1
30	109	30	41.2
45	115.9	45	40.6
9:00	121.2	5:00	40.1
15	123.5	15	39.9
30	-	30	-
45	133.1	45	33.5
10:00	135.5	6:00	28.5
15	135.4	15	25
30	136.4	30	23.2
45	136.4	45	19.8
11:00	134.1	7:00	16
15	128.7	15	16.7
30	119.5	30	9.6
45	113.1	45	0
12:00	104.7	8:00	0
15	95.7	15	- 1.5
30	-	30	- 1.5
45	66.5	45	2.5
1:00	56.2	9:00	- 3
15	49.2	15	.7
30	-	30	.4
45	44.3		
2:00	44.4		
15	40.1		
30	-		
45	38.9		
3:00	39.9		
15	39.5		
30	-		
45	-		

```
DO YOU WISH TO CHECK INTERMEDIATE TIMES OF
THE DAY TO SEE IF THE POINTS YOU INPUT WILL
GENERATE REASONABLE ILLUMINANCE VALUES FOR THOSE TIMES?
=YES
INPUT THE NUMBER OF DAYLIGHTING CALCULATIONS
WHICH YOU HOPE TO INPUT TO EXPRESS THE DAYLIGHTING
EFFECTS FOR A DAY.(AN ODD NUMBER)
=3
LONGITUDE OF SITE
=122
NUMBER OF TIME ZONES WEST OF GREENWICH
=8
HOUR OF LOCAL SUNRISE. JN21
=5.83
NATURAL ILLUMINANCE CALCULATED AT:  9.36 12.89 16.42
=123.5 56.2 41.2
HOW MANY INTERPOLATED POINTS DO YOU WISH TO CHECK?
=30
INPUT TIME OF DAY FOR INTERPOLATION CHECK
=6
INTERPOLATED ILLUMINANCE VALUE IS:  9.79
=6.5
INTERPOLATED ILLUMINANCE VALUE IS: 37.94
=7
INTERPOLATED ILLUMINANCE VALUE IS: 63.90
=7.5
INTERPOLATED ILLUMINANCE VALUE IS: 86.24
=8
INTERPOLATED ILLUMINANCE VALUE IS:103.83
=8.5
INTERPOLATED ILLUMINANCE VALUE IS:115.76
=9
INTERPOLATED ILLUMINANCE VALUE IS:122.35
=9.5
INTERPOLATED ILLUMINANCE VALUE IS:123.21
=10
INTERPOLATED ILLUMINANCE VALUE IS:119.14
=10.5
INTERPOLATED ILLUMINANCE VALUE IS:111.11
```

```
=11
INTERPOLATED ILLUMINANCE VALUE IS:100.30
=11.5
INTERPOLATED ILLUMINANCE VALUE IS: 88.02
=12
INTERPOLATED ILLUMINANCE VALUE IS: 75.54
=12.5
INTERPOLATED ILLUMINANCE VALUE IS: 63.98
=13
INTERPOLATED ILLUMINANCE VALUE IS: 54.23
=13.5
INTERPOLATED ILLUMINANCE VALUE IS: 46.83
=14
INTERPOLATED ILLUMINANCE VALUE IS: 41.96
=14.5
INTERPOLATED ILLUMINANCE VALUE IS: 39.48
=15
INTERPOLATED ILLUMINANCE VALUE IS: 38.91
=15.5
INTERPOLATED ILLUMINANCE VALUE IS: 39.57
=16
INTERPOLATED ILLUMINANCE VALUE IS: 40.62
=16.5
INTERPOLATED ILLUMINANCE VALUE IS: 41.24
=17
INTERPOLATED ILLUMINANCE VALUE IS: 40.66
=17.5
INTERPOLATED ILLUMINANCE VALUE IS: 38.33
=18
INTERPOLATED ILLUMINANCE VALUE IS: 33.93
=18.5
INTERPOLATED ILLUMINANCE VALUE IS: 27.42
=19
INTERPOLATED ILLUMINANCE VALUE IS: 19.06
=19.5
INTERPOLATED ILLUMINANCE VALUE IS:  9.33
=20
INTERPOLATED ILLUMINANCE VALUE IS: -1.08
=20.5
INTERPOLATED ILLUMINANCE VALUE IS:-11.41
```

```
DO YOU WISH TO CHECK INTERMEDIATE TIMES OF
THE DAY TO SEE IF THE POINTS YOU INPUT WILL
GENERATE REASONABLE ILLUMINANCE VALUES FOR THOSE TIMES?
=YES
INPUT THE NUMBER OF DAYLIGHTING CALCULATIONS
WHICH YOU HOPE TO INPUT TO EXPRESS THE DAYLIGHTING
EFFECTS FOR A DAY.(AN ODD NUMBER)
=5 <--
LONGITUDE OF SITE
=122
NUMBER OF TIME ZONES WEST OF GREENWICH
=9
HOUR OF LOCAL SUNRISE, JN21
=5.83
NATURAL ILLUMINANCE CALCULATED AT:  8.18 10.54 12.89 15.24 17.60--
=97.9 136.4 56.2 39.5 35
HOW MANY INTERPOLATED POINTS DO YOU WISH TO CHECK?
=30
INPUT TIME OF DAY FOR INTERPOLATION CHECK
=6
INTERPOLATED ILLUMINANCE VALUE IS:  6.51
=6.5
INTERPOLATED ILLUMINANCE VALUE IS: 26.00
=7
INTERPOLATED ILLUMINANCE VALUE IS: 46.53
=7.5
INTERPOLATED ILLUMINANCE VALUE IS: 68.18
=8
INTERPOLATED ILLUMINANCE VALUE IS: 90.11
=8.5
INTERPOLATED ILLUMINANCE VALUE IS:110.62
=9
INTERPOLATED ILLUMINANCE VALUE IS:127.45
=9.5
INTERPOLATED ILLUMINANCE VALUE IS:138.38
=10
INTERPOLATED ILLUMINANCE VALUE IS:141.75
=10.5
INTERPOLATED ILLUMINANCE VALUE IS:137.04
```

```
=11
INTERPOLATED ILLUMINANCE VALUE IS:125.03
=11.5
INTERPOLATED ILLUMINANCE VALUE IS:107.74
=12
INTERPOLATED ILLUMINANCE VALUE IS: 88.02
=12.5
INTERPOLATED ILLUMINANCE VALUE IS: 68.92
=13
INTERPOLATED ILLUMINANCE VALUE IS: 53.08
=13.5
INTERPOLATED ILLUMINANCE VALUE IS: 42.19
=14
INTERPOLATED ILLUMINANCE VALUE IS: 36.69
=14.5
INTERPOLATED ILLUMINANCE VALUE IS: 35.82
=15
INTERPOLATED ILLUMINANCE VALUE IS: 37.97
=15.5
INTERPOLATED ILLUMINANCE VALUE IS: 41.13
=16
INTERPOLATED ILLUMINANCE VALUE IS: 43.44
=16.5
INTERPOLATED ILLUMINANCE VALUE IS: 43.61
=17
INTERPOLATED ILLUMINANCE VALUE IS: 41.12
=17.5
INTERPOLATED ILLUMINANCE VALUE IS: 36.17
=18
INTERPOLATED ILLUMINANCE VALUE IS: 29.48
=18.5
INTERPOLATED ILLUMINANCE VALUE IS: 21.91
=19
INTERPOLATED ILLUMINANCE VALUE IS: 14.16
=19.5
INTERPOLATED ILLUMINANCE VALUE IS:  6.61
=20
INTERPOLATED ILLUMINANCE VALUE IS: -0.75
=20.5
INTERPOLATED ILLUMINANCE VALUE IS: -8.14
```

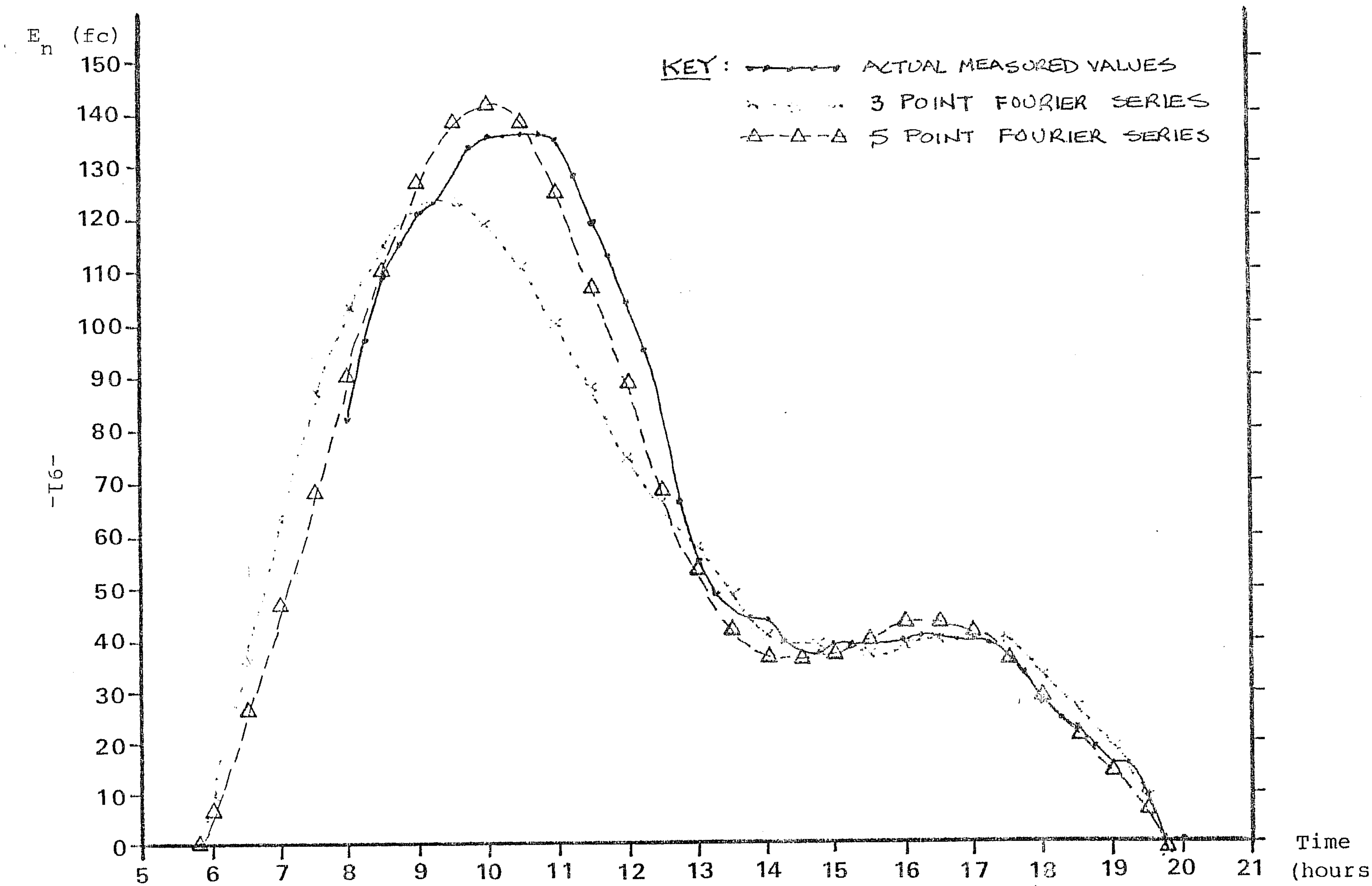


Fig. 2 Comparison of actual measured values vs. Fourier series curve generated from 3 and 5 input points. Measured points taken from P.G.& E., zone 4, southeast facing, drapes closed, clear day on June 28, 1980.

IV DESCRIPTION OF DAYHELP OPTION

The main program requires daylighting input at certain times of the day, centered around solar noon, but does not do the actual daylighting calculations themselves. Because of this, the times of the day for which daylighting values are expected must be known so that these values can be obtained prior to running the main program. Program DAYHELP serves this function by supplying the proper times of the day, given the site location and the civil sunrise for March 21, June 21, and December 21.

Another capability of DAYHELP is that of testing the reasonablness of an E_n curve built by Fourier series techniques from a small number of calculated input data points. Once daylighting values are known for the required input times, the total E_n curve can be constructed and intermediate times can be checked for the interpolated value of E_n built by the series. In this way, a determination can be made as to whether the few data points specified represent actual conditions close enough, or if more data points must be input to build the curve.

An example of the use of this program, which is in the interactive time sharing mode, is included below. As these options are independent of each other, some input data must be repeated for each option.

```
DO YOU NEED HELP IN DETERMINING THE APPROPRIATE
TIMES FOR WHICH DAYLIGHTING CALCULATIONS MUST BE DONE?
=YES
HOW MANY DAYLIGHTING CALCULATIONS DO YOU HOPE TO DO FOR EACH DAY?
=3
LONGITUDE OF SITE
=100
NUMBER OF TIME ZONES WEST OF GREENWICH
=7
HOUR OF SUNRISE IN CIVIL TIME  MR21
=7
```

```
CALCULATE NATURAL ILLUMINANCE AT:  9.29 11.79 14.29
HOUR OF SUNRISE IN CIVIL TIME, JN21
=6
CALCULATE NATURAL ILLUMINANCE AT   8.69 11.69 14.69
HOUR OF SUNRISE IN CIVIL TIME, DC21
=8
CALCULATE NATURAL ILLUMINANCE AT:  9.63 11.63 13.63

DO YOU WISH TO CHECK INTERMEDIATE TIMES OF
THE DAY TO SEE IF THE POINTS YOU INPUT WILL
GENERATE REASONABLE ILLUMINANCE VALUES FOR THOSE TIMES?
=YES
INPUT THE NUMBER OF DAYLIGHTING CALCULATIONS
WHICH YOU HOPE TO INPUT TO EXPRESS THE DAYLIGHTING
EFFECTS FOR A DAY.(AN ODD NUMBER)
=3
LONGITUDE OF SITE
=100
NUMBER OF TIME ZONES WEST OF GREENWICH
=7
HOUR OF SUNRISE IN CIVIL TIME, MR21
=7
NATURAL ILLUMINANCE CALCULATED AT:  9.29 11.79 14.29
=75 100 125
HOW MANY INTERPOLATED POINTS DO YOU WISH TO CHECK?
=13
INPUT TIME OF DAY FOR INTERPOLATION CHECK
=7
INTERPOLATED ILLUMINANCE VALUE IS:  8.61
=8
INTERPOLATED ILLUMINANCE VALUE IS: 46.28
=9
INTERPOLATED ILLUMINANCE VALUE IS: 70.65
=10
INTERPOLATED ILLUMINANCE VALUE IS: 81.95
=11
INTERPOLATED ILLUMINANCE VALUE IS: 89.84
=11.5
INTERPOLATED ILLUMINANCE VALUE IS: 95.70
=12
INTERPOLATED ILLUMINANCE VALUE IS:103.38
=12.5
INTERPOLATED ILLUMINANCE VALUE IS:112.21
=13
INTERPOLATED ILLUMINANCE VALUE IS:120.63
=14
INTERPOLATED ILLUMINANCE VALUE IS:127.51
=15
INTERPOLATED ILLUMINANCE VALUE IS:107.60
=16
INTERPOLATED ILLUMINANCE VALUE IS: 55.80
=17
INTERPOLATED ILLUMINANCE VALUE IS:-15.09
```

The graph of Figure A.1 shows what could happen with only three input points. Although the Fourier series reproduces the input data points exactly, the "reasonable" curve created from these points may, in fact, differ quite a bit from the actual E_n curve known from calculations or measurements. When variations this large exist, the user should probably increase the number of input values of E_n needed to construct the curve.

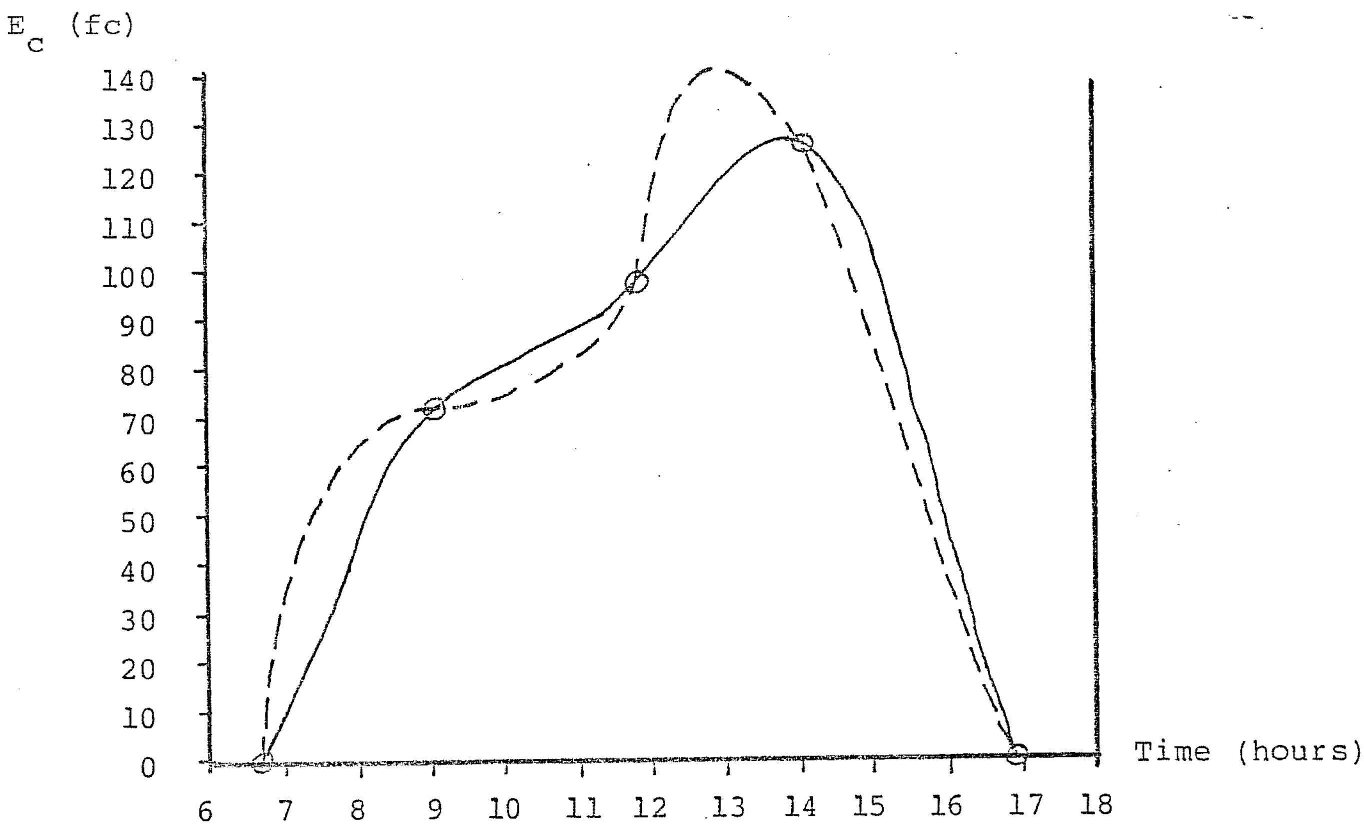


Fig. A.1 Solid line represents curve created by Fourier series; dashed line represents known daylighting variations over the day. Points circled are input values of E_n

V CONCLUSION

This report, along with the delivery of a computer tape of the FORTRAN code of the program completes the requirements for work to be done in the Technical Scope of Work for subcontract 4500910. In that sense, this signals an end to the project, but it also means the beginning of perhaps a more important one - supplying the program for use in the public domain. This project can be considered a success only after the program has been tested enough to be error free and then supplied to those interested in using it. The d velopers of the program see it as a very useful tool to assist in the lighting design process, and its general use should greatly enhance the energy related analysis of lighting control systems.

Further testing of the program by several users is necessary to surface any remaining flaws in the code and comparison calculations against other test installations will also prove useful. With the increasing availability of large quantities of daylighting information, a more accurate model of yearly variations of energy consumption might be possible by altering the current program to accept more daylighting input values.

ACKNOWLEDGEMENT

This work was supported by the Assistant Secretary for Conservation and Renewable Energy, Office of Building Energy Research and Development, Building Equipment Division, of the U.S. Department of Energy under Contract No. W-7405-ENG-48.